The Morphodynamics of Motunau Beach and Management Implications

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Late afternoon at Motunau Beach looking east over Sandy Bay and the cliffs. 18th June 2007.

I. Abstract

Motunau Beach is situated upon a small coastal promontory which is approximately 3 km in length. Around this promontory a complex of coastal processes are interacting. In the past there has been concern for people's property due to eroding sandstone cliffs. In response to the erosion hazard piecemeal structural solutions have been sought; however, due to their short longevity have proved inadequate.

Based on regular shoreline profiling and observations in conjunction with a broad international literature base, the processes of wave refraction, cliff erosion, river mouth dynamics, and sand beach adjustment have been discussed. Sediment transport pathways have been inferred based upon the natural and human processes around the promontory and the morphological response since the 1950s.

To analyse the coastal processes and morphological change at Motunau Beach a combination of qualitative and quantitative research methods have been used. The field study period of three months, July to September 2009, has focussed on the short-duration and high-frequency processes of change and nested within a broader context of coastal change since the 1950s.

Initial results suggest that between the years 1950 to 1968 there was a loss of beach width on Sandy Bay of approximately 25 m. This was then followed by an increased rate of cliff erosion during the 1980s. Analysis of historical hindcast wave data since 1979 suggests the wave climate at Motunau is not distinctive from the rest of the east coast; however, the processes of wave refraction within the nearshore create a turbulent and dynamic nearshore wave environment which has implications on shoreline morphology. Results from this study indicate that nearshore sediment supplies are being exhausted by a increasing wave height of approximately 4 mm yr^{-1} since 1979. The turbulent wave environment of the nearshore zone at Motunau Beach is encouraging the offshore transfer of nearshore sediment supplies to a depth beyond the reworking of waves during swell condition. This has obvious implications for the long-term shoreline morphology at Motunau and shoreline protection from high-intensity low frequency wave events.

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V. Acknowledgements

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Chapter One

1.1 Introduction

The following chapter outlines the Motunau study area along with the five research questions that have been developed in order to guide this research. Section 1.2 highlights the gap in the research that currently exists in the knowledge base of the Motunau Beach coastal processes; therefore, giving a rationale for this current study. Section 1.3 is a description of the Motunau Beach coastal processes. Section 1.4 outlines the aims and introduces the research questions. Section 1.5 outlines the initial hypothesis prior to field investigations. Section 1.6 is a breakdown of the methods that will be used during the July to September field period. Section 1.7 reviews the previous research that has been undertaken in Motunau. Section 1.8 outlines the key points discussed throughout this chapter.

1.2 Thesis Statement

This thesis describes the coastal processes active in the Motunau Beach coastal environment for the purposes of informing future management. The primary aim of this thesis is to use a composite of quantitative and qualitative research techniques to provide morphological observations of the shoreline. The field work component of this thesis will link the small-scale and high-frequency morphological processes of change to a larger timescale process of coastal change. The rationale for wanting to study these small-scale and high-frequency processes is that in the past shoreline change has been linked to large one-off events. The day to day fluctuations in sediment level may provide insight into processes that build up to the large one-off cliff collapses or beach scouring.

The Motunau promontory is a site characterised by the compound interaction of coastal processes. Although each of the individual processes are not unique in coastal literature the way they interact at Motunau is potentially distinctive. Coastal cliff erosion, erosion of sand beaches, and island wave refraction, are a few processes that will be discussed in this thesis. The way the shoreline has responded to this complex of coastal processes at Motunau Beach highlights that there is not only a research gap in understanding this form of coastal environment in New Zealand and internationally, but also there is a gap in the site specific coastal information about the

Motunau area. An understanding of the coastal processes that are specific to Motunau is important for the sustainable human use and hazard management of the Motunau coastal system. This lack of available information has resulted in the conflicting use of the environment since the 1950s.

1.3 Motunau Beach Coastal Promontory: The Study Area

The Motunau Beach promontory is 2.5 km in length and is situated approximately 80 km northeast of Christchurch on the east coast of the South Island. The promontory is made up of steep roughly 90˚ plunging sandstone coastal cliffs, a composite sand beach, a remnant sand dune system some 500 m in length, rock platforms, and the mouth of the Motunau River (Figure 1.1).

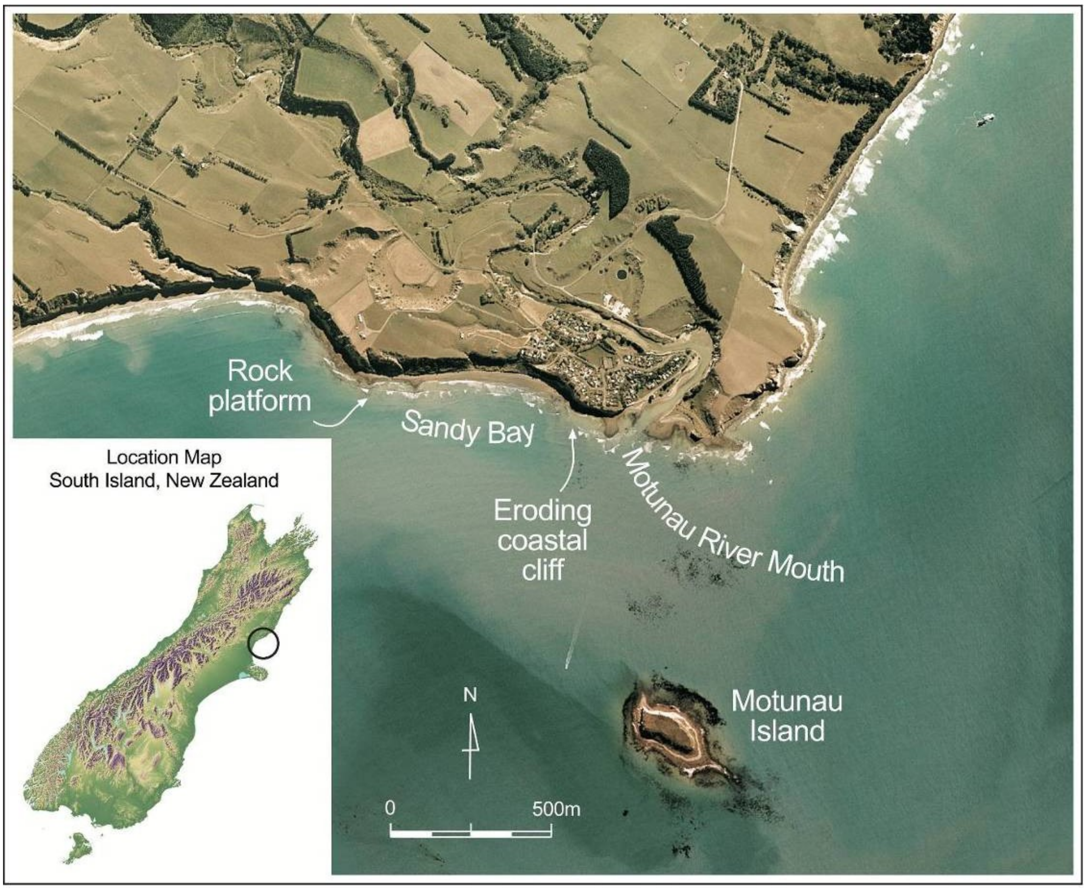


Figure 1.1 Study location and the mix of coastal landforms that make up the Motunau promontory. Aerial photograph sourced from Linz 2004/05.

The cliffs at Motunau Beach are Greta Siltstone and have a marine sedimentary origin. They are Miocene (23.03 to 5.33 ma yr BP) to Pleistocene (2.488 ma to 12,000 yr BP) in age (R.W. Morris and Associates, 1987; Barrell, 1989). Approximately 1 km south offshore of the river mouth lays Motunau Island, Canterbury's largest offshore island. The island is also characterised by steep plunging cliffs. The river mouth is orientation towards the south. The lower reaches of the Motunau River catchment are constrained within remnant river terraces which is indicative of the active uplift of the area by the Motunau Beach fault line (Barrell, 1989). Uplift rates are in the range of 1.5 to 1.7 mm yr^{-1} (RETECH, 1990).

The dominant sediment sizes on Sandy Bay and around the river mouth consist of coarse grained sand with an average size of 0.13 mm or 2.94 phi (Ecan, 1995; Foster, 2008). This coarse grain sand is thought to be brought northwards by the net littoral drift from the south (Foster, 2008). The extent of sands and gravels along the promontory is potentially the result of seasonal variations in wave energy and tidal levels. This variation in sediment type and size is a good indicator of wave energy variation along the coastline (Figure 1.2).

Figure 1.2 View looking west towards Motunau River mouth, the eroding coastal cliffs, and Sandy Bay. Motunau Island to the left out of view. Note the variable sediment sizes; gravels and boulders, along with finer sands in the river channel (August, 2009).

It is known that Motunau was never permanently settled until European arrival in the early 1800s. However, an earlier Maori presence in the area has been documented (New Zealand Historic Places Trust, 1969). A small coastal settlement has been built around the use of the Motunau River mouth for commercial and recreational fisheries access. Conflict over the use of the coast began in the early 1950s when there appeared to be an accelerated rate of cliff retreat. At this time Sandy Bay was also experiencing a loss of beach width. Numerous human interventions were carried out in order to attempt to slow this rate of change. Examples of this include; rock revetment walls, and wire gabion baskets filled with stone. To date a combination of hazards still affects the Motunau promontory and the people that regularly interact with it. These hazards include; the continued erosion of the coastal cliffs, Motunau River mouth dynamics and navigation safety, and also a volatile nearshore wave climate. Despite these hazards there remains a lack of effective mitigation strategies.

1.4 Aims

The aim of this thesis is to investigate and describe the physical along with the human dimensions of the Motunau promontory which have lead to morphological change. To achieve this aim a series of research questions have been developed in order to guide this research. The research questions are as follows;

Question 1: What are the processes causing cliff erosion at Motunau?

Since the 1950s it is well known amongst Motunau residents that there has been an increased rate of cliff retreat in Motunau. Barrell (1989) suggests this is occurring at a rate of 1.6 m yr^{-1}. Storm events in combination with subaerial processes are responsible for sudden large-scale loss of cliff material. Little attention has been paid to investigating the everyday processes of wave attack on the foot of the cliff and the fluctuations in the level of the beach adjacent to the cliffs. Past geological studies have focused on mechanical stresses and failure mechanisms within the cliff though not on the external controls such as tides and wave patterns within the nearshore zone.

Question 2: How is the bathymetry of the nearshore zone linked to changes in shoreline morphology?

In the shadow of Motunau Island lies the eroding coastal cliff. This zone exhibits a highly dynamic and unpredictable wave climate. This presents a hazard to coastal navigation and is also a threat to the property atop the cliffs. Understanding the controls on the local wave climate, both offshore and nearshore, requires an understanding of the bathymetrical controls on wave approach and the mechanisms of wave energy focussing. Frihy et al., (2008) discusses the importance of recording bathymetric changes and shoreline fluctuations when evaluating hazards at the coastline. There is an existing arrangement of shoreline profiles at Motunau that are annually surveyed by Environment Canterbury (ECan). There has been no attempt to record or analyze the nearshore hydrographic area and the accompanying wave environment in Motunau Beach. The relationship between wave energy and shoreline profiles is closely linked and has been overlooked at Motunau.

Question 3: Is there a relationship between rock platform lowering at the base of cliffs and the retreat of Sandy Bay?

There has been a loss of beach width on Sandy Bay which lies to the west of the cliffs. Historically sediments within Sandy Bay accumulated in a pocket beach that formed between two headlands. Since the 1950s it has been subject to the net loss of beach sediment. Explanations to why this has occurred are unclear and its significance has been overlooked. The processes of rock platform formation and basal lowering are well recognized in international coastal literature. What are the effects of these processes in Motunau? Is it the large low-frequency storm events that erode the cliffs or the high-frequency and small-scale events that are of more significance? Barrell (1989) suggests the down wasting rates of the rock platform in Motunau are in the range of 4.5 to 61 mm yr^{-1}.

Question 4: Has the stabilising of the river mouth affected the supply of sediment to the base of the cliff and Sandy Bay inducing erosion?

In 1971 an area of rock was removed from the base of the cliffs to stabilize the banks at the mouth of the river (RETECH 1990, 1991a/b). Not long after the river was confined by two large rock revetment walls that limit the amount of natural avulsion and hydraulic adjustment to variable flow regimes. Has this restricted the amount of sediment supply to Sandy Bay and the base of the cliffs?

Question 5: What are the management implications for the area in the next 10 years?

The naturally formed river mouth bar at Motunau has never been officially studied. Understandings of its morphology and dynamics are minimal. The bar has caused recreational boats to capsize while entering and leaving the river mouth resulting in the increased risk of damage to commercial vessels and equipment. The fishermen who use the river mouth also run the risk of more serious accidents occurring with the potential loss of life. Property development continues in Motunau atop the Sandy Bay cliffs. If the loss of beach width at Sandy Bay continues at its present rate there will be a continued need for coastal hazard management in the form of property removal or banning of development in Motunau despite the warnings.

1.5 Hypothesis

The hypothesis is that the current morphology of Motunau Beach has not solely been shaped by the influence of waves. Instead the ongoing interactions between the river mouth, the orientation of the promontory, the role the offshore island has on the form of waves, and lastly the active uplift in the area. Furthermore, the erosion of this area is part of a much larger-scale process of coastal change related to global sea level rise. The apparent increased rate of erosion during the 1950s is potentially the result of the expansion of the small coastal community.

1.6 Methods

A preliminary investigation of Motunau Beach in 2008 revealed that the most dynamic time of year, in terms of wave climate and beach profile adjustment, was between the months July to September. In 2009 the same three month period was selected in order to get the most drastic changes in field data and observations. Methods that were used over the three month study period of Motunau Beach incorporated a combination of qualitative and quantitative techniques. These included historical photographs of the area, and historical wave data using the Wave Model (WAM). The following is a breakdown of the methods that will be used to answer each of the research questions.

To answer question one an array of international and national coastal literature on the processes of cliff retreat was consulted. This it is hoped put the Motunau cliff retreat in context. Oblique historical photographs provided by local residents were used in order to gauge how the form of the cliff has changed since the 1950s. This visual comparison gave an indication of the coastal processes that were, and currently are, interacting with the cliff. Vertical aerial photograph comparisons were carried out using GIS mapping techniques, in particular, the orthorectification of aerial photographs since the 1950s. This gave another visual comparison of land use changes since early settlement of the area along with the shoreline and cliff line changes. To accurately align the set of images a series of ground control points (GCPs) that were distinguishable in each photograph were identified. This was done using Arc GIS 9 version 9.3.1. These were then correlated to the coordinate system of

NZ Map Grid which aligned with the most recent orthorectified aerial photograph. This was supplied by Land Information New Zealand (LINZ) with a date of 2004. On each of the photographs the edge of the dune scarp and the edge of the cliff line was digitised. This is because they were two clearly distinct features. Shape files were then input into ARCMAP software, which was then overlaid over the 2004 orthorectified image. To accompany this, a large tension crack found atop the cliff was regularly recorded and the width of the crack measured. It was hoped this would give an indication of movement in relation to storm events that occur. Also a large debris slump was regularly measured to portray the influence of wave energy and sediment removal from the foot of the cliff.

To answer question two international literature was used to discuss the relevance of underwater features and their effects on wave form, sediment transport directions, and shoreline morphology. The wave climate of the nearshore zone was recorded through manual observations and related to available bathymetry data. The most detailed hydrographical chart available was that of the Kaikoura Peninsula to the Banks Peninsula 1:200,000 scale chart NZ63 with a date of 4/1998, also available from LINZ. To analyse the way waves are refracted into the Motunau area and along the contours of the promontory, a single line wave refraction technique was used. This method is outlined in the Shore Protection Manuel (1984), and was also used in the master’s thesis by F. M. Fahy (1986) Sand Aggradation in Caroline Bay, Timaru. More recently this technique has been used by the University Of Canterbury’s Geography Department to assist students in constructing wave refraction diagrams. This graphical construction of refraction diagrams provides a very general interpretation of the wave refraction process for a single wave as it progresses from the deeper offshore waters into shallower nearshore water. To look at the effects of the average wave heights on shoreline morphology the dimensions of the waves were kept constant at a 2 m height with a 10 s interval. This technique provided an understanding of the potential wave energy distribution and sediment transport directions along the Motunau coastline. This was also accompanied by observations and photographs.

In order to answer question three and interpret any seasonal trends in wave characteristics, 20 year hindcast (1979 to 1999) and 10 year nowcast (1997 to 2008) wave data supplied by the National Institute of Water and Atmospheric Research

(NIWA) was used. This wave data uses input winds from the European Centre for Medium-Range Weather Forecasts (ECMWF) to drive a WAM wave generation model. This wave data was generated at a point around the 50 m depth contour off the coast of the Motunau promontory. The data has been adjusted for wave refraction up to the 10 m depth contour which lies just seaward of Motunau Island. Therefore, is not representative of the shoreline wave climate at Motunau. This wave climate analysis was used to relate the responses in shoreline morphology to wave energy. To interpret this wave data Microsoft EXCEL was used and the data was broken up into 22.5° directional bins. This is so that the influence of each wave direction could be interpreted. From this average wave heights and approach direction were recorded. This historical data was then used to put the 2009 field period into context.

To answer question four and quantify the amount of variation at the mouth of the Motunau River the Environment Canterbury (ECan) profile H2554 was regularly surveyed using a theodolite. This profile was abandoned in 1998 by ECan. In 2008 it was regularly surveyed for my Geography 420 research project. Understanding the river mouth processes is vital for its successful management and in the past has been seriously overlooked. The river mouth has been drastically altered since early human settlement in Motunau. The effects of this have not been fully acknowledged, as a result we are faced with a serious navigation hazard. An understanding of the river mouth and how its physical processes of hydraulic adjustment fit within the compound of coastal processes active on the Motunau promontory is important if a new design of rock groyne or channel guide is to be implemented in the future. In association with this river mouth survey, three beach profiles along the length of Sandy Bay were established, as well as, surveying the existing ECan profile H2458. It was hoped these shoreline surveys would give insight into beach adjustments and the amounts of gross sediment envelope change between surveys over the study period. Furthermore, give an indication of responses in shoreline morphology as a result of wave energy and sediment distribution along the shoreline. The elevation data from the five shoreline profiles was collected using a theodolite and prism. The surveys on Sandy Bay were set up at beach level and large steel stakes were hammered into the sediment so that the position of each profile could be repeated. Each survey was divided into two sections. Firstly a seaward section, whereby the theodolite faced out to sea through the breakers. The prism went beyond the breakers as far as possible in order to best represent the lower section of the beach profile. The second section of the survey was where the theodolite was swivelled 180° in order to record the dune scarp and bank of the beach profile.

Question five will be based on the analysis of the shoreline profile adjustments. This was accompanied by field observations and the findings from the other research techniques used throughout this thesis. Predictions of future shoreline morphology were based upon the cliff erosion mechanisms outlined in available literature, sand beach loss and beach adjustments, along with historical river mouth dynamics.

1.7 Previous studies in Motunau Beach

The reason for this form of descriptive investigation of the Motunau coastal environment stems from the lack of information on the current coastal processes. Previous studies have been incomprehensive as they have focused on individual facets of the region, such as geological background or biological significance. They lacked the ability to draw together and relate the variety of physical processes that are interacting.

Jobberns and King (1933) provide one of the earliest accounts of the geology of the Motunau area. They discuss in detail the origin of the Motunau Plain. They provide a description of depositional sequences of covering beds and processes of river cutting. There is a focus on the formation and origin of Motunau Island. Little is discussed in the way of coastal erosion processes in the area.

In another early account of Motunau Beach Cox et al., (1967) describes in good detail the origin of Motunau Island also describing it as a remnant of the Motunau plain, cut off by marine erosion and sea level variations which have occurred in the recent postglacial Quaternary era. Here we begin to see the first acknowledgement of coastal erosion on the area along with the role of heavy storms and the role of rock beaches to dissipate the wave energy. There is an historical account of the role of Maori and early European settlement and associated land use changes in Motunau.

In an article by Herzer and Lewis (1979) a series of seismic profiles were carried out by BP, Shell and Gulf Oil off the coast of the Motunau promontory. These surveys confirmed the existence of a large buried submarine canyon. This canyon could have potentially been a sink for early Pleistocene debris flows. The buried canyon is 20 km wide and 65 km in length coming as close as 8 km to the present Motunau shoreline.

Interesting features of this buried canyon, that may still be affecting current coastal processes, are the series of small feeder channels that were too complex to be resolved in the surveys (Herzer and Lewis, 1979). The growth of the modern Pegasus Canyon resulted in the burial of the Motunau Canyon which began approximately 400,000 yr BP and was in-filled by 128,000 yr BP.

In 1985 Dr R.M. Kirk was contacted in regard to the accelerated rate of cliff erosion. After a series of site investigations he suggested the increased result of erosion could be attributed to the rock stripping from the base of the cliffs. There was no thorough description of the combined coastal processes that could have been the cause. Periods of severe storms could have increased the relative size of the cliff headland. The report did not go into detail about mechanisms of ocean current directions or the effects of bathymetry on shoreline morphology.

R.W. Morris and Associates Consulting Engineers (1987) were involved in Motunau in the early 1980s after the first official reference to coastal instability was recognised in the 1970s. They provide a detailed geological background of the area with a specific focus on cliff retreat and rock platform processes. They also briefly mention the processes responsible for the retreat prior to human intervention as sea level variation over the last 5,000 years. They do not describe in detail other key coastal processes that are of current significance, such as the processes of littoral drift, or the dynamic nature of the river mouth.

In conjunction with R.W Morris and Associates Consulting Engineers (1987, 1988) a series of RETECH reports (1990, 1991a, and 1991b) were published. These reports approached the issue of cliff retreat from an engineering position, recommending possible non-structural solutions, such as the establishment of a ‘Motunau Residential Coastal zone’. These RETECH reports did predict that despite possible structural solutions cliff retreat is inevitable, highlighting that a more comprehensive understanding of the coastal environment and coastal processes is required. The three RETECH reports (1990, 1991a and 1991b) identify one problem in the area, cliff retreat, and recommend solutions to this issue. These reports are primarily focused around the installation of the wire gabion wall along the foot of the cliff. These reports do not go into depth over the other coastal processes that are in the area. These reports provide a good first glance description of the processes.

Barrell (1989) is a master’s thesis in engineering geology that provides a very comprehensive assessment of the Motunau Beach promontory and the associated geology. He provides tectonic uplift rates by the Motunau Beach Fault and the wider Motunau fold belt. Barrell (1989) also provided down wasting rates of the rock platform at the foot of the cliff; furthermore approximate dates of the sea level positions during the last glacial and interglacial period. He also proposes theories as to the accelerated cliff erosion of the 1950s.

Owens et al., (1994) discussed the risk to houses located on the cliff top at Motunau Beach. Defining hazards as the “unwanted interaction between a natural event system and a human use system such as to lead to a threat to assets, actual damage to assets and/or loss of life” (Owens et al., 1994, pg 35). This is evidence to support that the problem of coastal erosion had been identified in Motunau on numerous occasions over the last two decades. Furthermore, erosional processes and mitigation options had been proposed to the North Canterbury Catchment Board (NCCB), the Regional Water Board (RWB) and the Hurunui County Council (HCC) (Owens et al., 1994). Yet little has been done in the way of coastal management of the Motunau Beach coastal zone. More attention is warranted in regard to the coastal erosion in Motunau. Large storm initiated erosion events can be expected to threaten the lives and property of people along the entire Canterbury coast more than once in any 100 year period (Owens et al., 1994).

Anderson (1999) provides a reassessment of the gabion wall constructed in the early 1990s. There is a description of the process of cliff erosion and mechanisms by which wave attack occurs, for example, undercutting of the toe, biological and mechanical weathering processes, and also a brief description of management responses such as beach conservation and building restrictions. Anderson (1999) concludes that “geology, geomorphology and various processes peculiar to Motunau collaborate to produce an area very susceptible to change”. Backing up my initial hypothesis that a combination of coastal processes are leading to the continued erosion of the Motunau promontory.

Marshall (2005) is a master’s thesis in engineering geology that looks at the critical height concept of the Motunau cliff and structural failure. Once again providing detailed geology of the cliffs and suggesting an enhanced rate of collapse could be related to moisture content in the area due to poor drainage.

Despite the fluctuation of interest surrounding the coastal erosion in the early 1990s, it appears from the current literature review that 1991 was the last time there was active interest from outside agencies in the processes that were affecting people and the coast. Recent management strategies include dredging of sands from the lower reaches of the river mouth in order to maintain a navigable passage to and from the sea. Consent for this has been granted by ECan. More recently there has been a new jetty constructed and reinforcements to the river bank have been made by a contractor in order to stop erosion of the main access road down to the parade. There have been numerous attempts by local residents to maintain existing jetty structures. These include the likes of beer bottles and wire as fill, along with large rubber tractor tyres added to the channel guides. This piecemeal approach to the management of Motunau Beach has proved temporarily effective nonetheless unsustainable in the long-term.

The review of previous studies has given this thesis a context in which to emerge. A research gap has been identified which potentially has been inhibiting the successful implementation of management strategies around Motunau Beach.

1.8 Chapter Summary

The purpose of this investigation has been presented in this chapter along with the gap that currently exists in the understandings of coastal processes around Motunau Beach. Chapter Two uses a combination of international as well as national literature to review the individual processes of cliff erosion, sand beach morphology, the dynamics of river mouths, and the processes associated with wave refraction. Chapter Three outlines the geological background of Motunau, introducing key theories on which much of the current understandings have been based, also introducing the key players involved with the use of the coastline and river catchment. Chapter Four introduces the effects of local climate on the areas. Chapter Four also introduces the 20 year wave hindcast and 10 year nowcast wave data that is used throughout this thesis to analyse wave patterns and the possible links to changes in the shoreline morphology. Chapter Five outlines the key results from the three month study period July to September 2009. Chapter Six is the discussion and interpretation of the results which tie in observations and theories about shoreline responses to the complex of coastal processes. Chapter Seven is a summary chapter highlighting key findings and the limitations of this research.

Chapter Two

Literature Review

2.1 Introduction

Chapter One gave a brief introduction to the study area of Motunau Beach and outlined the aims and methods of this thesis. Chapter Two will discuss the environment and key management issues of Motunau Beach using an in-depth combination of both national and international literature examples. Section 2.2 examines the processes of coastal cliff erosion, while 2.3 discusses the processes of sand beach adjustments. Section 2.4 explores river mouth dynamics and exchange between the ocean. Lastly section 2.5 discusses in detail the processes of wave refraction and the role nearshore bathymetry plays on modifying shoreline morphology.

Motunau Beach is an erosional coastline with estimated rates of loss at around the minimum values of 8 to 10 mm yr^{-1} (R.W. Morris and Associates, 1987). The shoreline is cyclically being cut back by both wave attack and sub-aerial weathering processes; or the processes that lead to the degradation of shoreline morphology above wave action. These include rainfall and runoff. Figure 2.1 is a summary of the terms that are continually repeated throughout Chapter Two in order to describe areas on the shoreline.

Coastal processes on erosional coasts commonly form sea stacks, coastal cliffs, and rock platforms. The way the Motunau Beach promontory protrudes out into the sea indicates that the rock type in this area is more resistant to forms of weathering and erosion that the surrounding shoreline. The Motunau Beach promontory consists of a combination of coastal processes within its length of 2.5 km. These include the eroding coastal cliffs, an eroding sand beach and sand dune system, the Motunau River mouth, and the largest offshore island in Canterbury, Motunau Island.

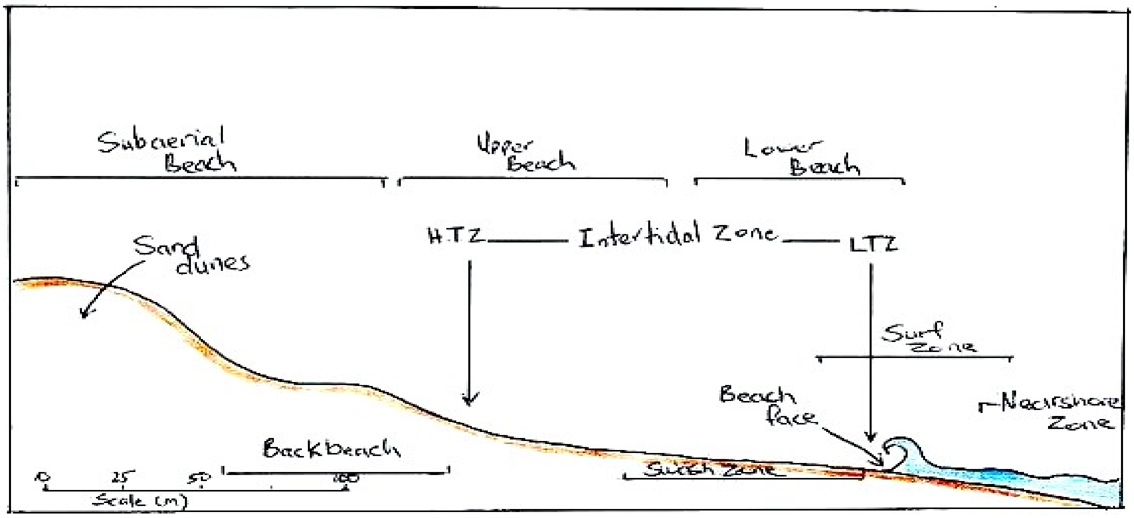


Figure 2.1 Outline of the terms used and their locations on the beach. (Modified from Patino, 2005, pg 97).

2.2 Coastal Cliff Erosion

Coastal cliffs occur along 80 % of the world's coastline. In New Zealand this equates to approximately one-quarter or 23 % of the shoreline (Gibb, 1984; Kennedy and Dickson, 2007; Lee, 2008). Cliffed shorelines pose a range of management implications including hazard management. The processes of wave attack, sub-aerial weathering, and human manipulation combine making coastal cliff environments complex and dynamic. Each coastal cliff environment exhibits its own magnitude, duration and sequence of erosional events. This explains the large regional variations in the rates and volumes of cliff collapse (Masselink and Hughes, 2003; Lim et al., 2009). The cliffs at Motunau consist of consolidated siltstone that is mantled by less consolidated marine and fluvial deposits which consist of larger gravels and pebbles. Atop these sediments there is layer of wind derived sediments known as loess (R.W. Morris and Associates, 1987; Barrell. 1989; Lumsden and Kirk, 1991; Marshall, 2005; Bell Geoconsulting Limited, 2008). The plunging volcanic cliffs present on Banks Peninsula south of Motunau, along with the harder more consolidated limestone cliffs north of Motunau on the Kaikoura Peninsula, are less readily eroded in comparison to the Motunau cliffs. The erosion of coastal cliffs is not solely dependent upon wave action. Instead the combination of wave action, sub-aerial weathering, rock type, and sea level history lead to the degradation of cliffed coastlines (Cambers, 1976; Ming Shih and Komar, 1994; Masselink and Hughes, 2003; Lee, 2008; Juracic et al., 2009). For example, the retreat of the coastal cliffs in southeast Ireland is not simply the result of rising sea level (Carter et al., 1987). Rates of cliff recession can be influenced by heavy rainfall, earthquakes, and bioerosional processes. These can function separately or together as efficient triggers of collapse. Bioerosion is the weathering and removal of rock by organisms. Organisms, such as bird life or burrowing animals, directly remove rock material weakening surrounding rocks, making the cliffs susceptible to mechanical or physical processes of erosion (Masselink and Hughes, 2003). Bioerosional processes are more efficient at generating instabilities than mechanical erosion at sea level (Juracic et al., 2009; Lim et al., 2009).

Physical weathering of a cliff face is responsible for the physical widening of cracks and existing weaknesses in the rock. Physical weathering processes include wet/dry processes, salt spray, tides, and rain. Salt spray weathering will occur when salt grains inside the rock capillaries absorb water and undergo a volumetric change, ultimately expanding and cracking the rock. This can then be combined with mechanical wave erosion and the resulting erosion of large segments of rock (Budetta et al., 2000; Masselink and Hughes, 2003). The exposure of the cliff face at Motunau suggests that this process of salt spray weathering potentially is occurring. Rates of recession differ from site to site depending on water seepage into cracks at the top of the cliff and the internal bedding structures within the cliff (Ming-shih and Komar, 1994). During the study period at Motunau a large tension crack atop the cliffs was located. This large crack potentially supports the process of water infiltration into the internal bedding of the cliff structure.

The local surroundings greatly influence the process of cliff retreat. For example, the local wave environment and the local climate are two variables that can manipulate the temporal rates at which weathering occurs (Masselink and Hughes, 2003). Shoreline morphology is the result of a localised balance of the materials involved within the landform and the variety of external agents acting upon them (Lim et al., 2009).

A coastal cliff system is divided into three zones; the cliff, the beach, and the offshore. The cliff system may extend 10 m or more landward of the cliff top edge to the cliff toe. The beach system is that from the cliff toe to the mean low water mark of spring tides. The offshore system extends from the mean low water mark of spring tides to a depth of 20 m (Cambers, 1975). Cliff-top recession and cliff-bottom recession can function separately (Pierre, 2006). This means a combination of wave energy and sub-aerial processes lead to coastal cliff erosion. However, Cambers (1976) argues the retreat of cliffs is primarily due to wave attack. The erosion of the cliff toe by wave action can lead to cliff collapse. This occurs when high tides, tidal surges, or storms attack the base of a coastal cliff removing material to form a notch (Figure 2.2). The notch expands as wave attack at the base of the cliff continues forming a cliff profile that is over steepened and less stable (Figure 2.3). With a rise in global sea level we expect this process to become more influential. Sea level rise occurs on two levels, a regional level dependent upon local tectonics and ocean currents, and a global level attributed to thermal expansion of the world's oceans and the melting of polar ice sheets (Cai et al., 2009).

The erosion of clay and sandstone cliffs in northern Boulonnais, France is closely related to shore platform dynamics (Pierre, 2006). The vertical erosion on the bedrock at the base of the cliffs leads to cliff collapse. The speed of this basal lowering is dependent on the material present at the base of the cliffs which can act as a buffer against wave attack.

Figure 2.2 A notch that has formed at the base of the cliffs at Motunau (photograph taken 2008).

Figure 2.3 A collapse has occurred as a result of the cliff profile becoming over steepened and less stable (photograph taken 2009).

After prolonged periods of weathering a cliff will slump and slide to form a slope at the base of the cliff. This temporary slope provides support for the over steepened cliff. When a high rate of debris removal exists a bare rock face at a constant angle will be maintained (Figure 2.4). If the rate of cliff collapse exceeds the removal of sediment by wave action then the material accumulates into a talus slope (Figure 2.5) (Masselink and Hughes, 2003). As illustrated by Figure 2.6, constant wave attack can remove the support from the base of the cliff transporting the eroded material downdrift, exposing the cliff toe again to repeat the process (Lee, 2008).

Figure 2.4 Bare rock face at the base of the cliff exists due to constant removal of material by wave action (photograph taken 2009).

Figure 2.5 In a section of cliff where wave energy does not regularly remove cliff debris a small talus slope has developed. Note the high tide level which is slightly seaward of the cliff foot (Photograph taken 2009).

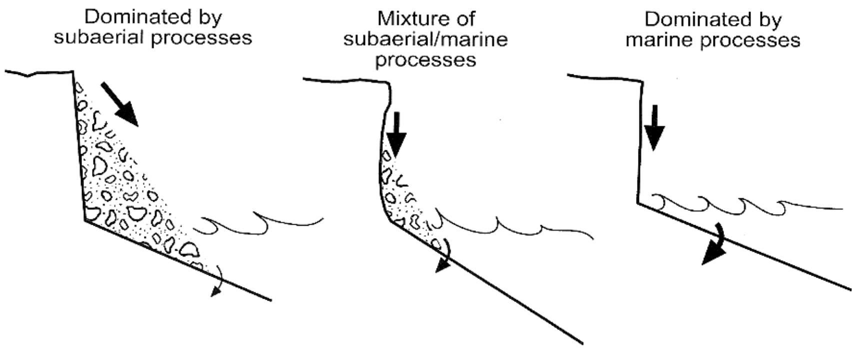


Figure 2.6 The cyclical nature of cliff retreat (Masselink and Hughes, 2003, page 265).

Cliff retreat is determined by the strength of the cliff material present, the imposed stresses, and the rate of wave attack on the cliff (Lee, 2008). With an increased rate of sea level rise we expect an enhanced rate of cliff recession in softer siliciclastic rocky coasts. This is the case, for example, along the western Italian coast (Juracic et al., 2009).

The more noticeable large-scale changes are part of a magnitude-frequency relationship. The smaller day to day events of erosion are important in determining the erosional mechanisms behind the large one-off erosional events (Lim et al., 2009). Less attention has been paid to the smaller events even though these are important when trying to understand the evolution of a landform (Lim et al., 2009). Smaller-scale events do not affect people and property as directly as large erosional events, thus tend to receive less attention. In order to better understand the position of future shorelines a detailed knowledge and understanding of short-term variability and beach morphology is required (Ruggiero et al., 2005).

In Motunau Beach it is believed that during the late 1950s there was a sudden increase in the rate of cliff collapse and shoreline erosion. However, this observed increase could be directly related to the level of permanent settlement increasing around that time. These larger-scale events were more readily noticed. Further explanations for a sudden rate of coastal cliff erosion include the formation of a bevelled cliff. Whereby a vertical cliff is formed during the last interglacial period (Figure 2.7), following the next glacial period sea level falls and the cliff is abandoned and mantled with debris. As sea level is raised wave attack on the cliff is resumed, thus steepening the base of the cliff (Masselink and Hughes, 2003).

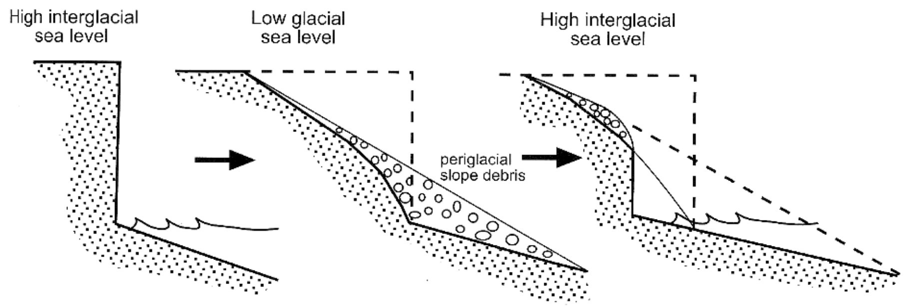


Figure 2.7 Model of a bevelled cliff (Masselink and Hughes, 2003, pg 269).

Coseismic (rapid tectonic) subsidence is another process that can lead to an apparent increased rate of cliff erosion. Coseismic subsidence is triggered by earthquakes when tectonic activities occur in the region of coastal cliffs. This can result in the rapid subsidence or emergence of the cliffs in the range of cm or mm. The rate of cliff erosion therefore adjusts to accommodate for the lower platform levels at the base of the cliff. In coastal environments where a cliff is attached or closely situated to a sand beach system, the process of rapid tectonic subsidence can lead to an increase in coastal dune erosion or nearby beach loss (Goff et al., 2008; Juracic et al., 2009). On the Oregon coast, USA, the input of fine sediment into a coastal cell and the rate of sediment transport downdrift occurred at a scale of approximately 300 years. This corresponded with a large subduction earthquake that occurred at the same time around 300 yr BP. This process linked a historical collapse event to sediment distribution along the beach downdrift of the eroding coastal cliffs (Ming Shih and Komar, 1994). This example shows that external drivers can influence the rate of cliff collapse. The amount of sediment that can come from these collapses is significant in down drift coastal processes, for example, coastal sediment budgets and shoreline morphology. The eroding coastal cliffs at Motunau Beach are situated in close proximity to a sand beach system to the west (Figure 2.8). To the north of these cliffs is the mouth of the Motunau River which is prone to sediment infilling during certain times of the year (Figure 2.9). It is therefore possible that this exchange of sediment from the beach and cliffs to the river mouth is occurring. It is also possible that the erosion of the headland cliffs is supplying sediment to the shoreline on either side of the cliffs. Appendix A is a timeline of events indicating the timing of earthquake events in relation to shoreline erosion. It is possible there is a relationship between earthquakes prior to 1950 and shoreline retreat. However, this relationship requires further investigation.

Figure 2.8 Looking east towards the coastal cliffs at Motunau Beach. Note the Sand beach system in the foreground which is attached to the western base of the cliffs (photograph taken 2009).

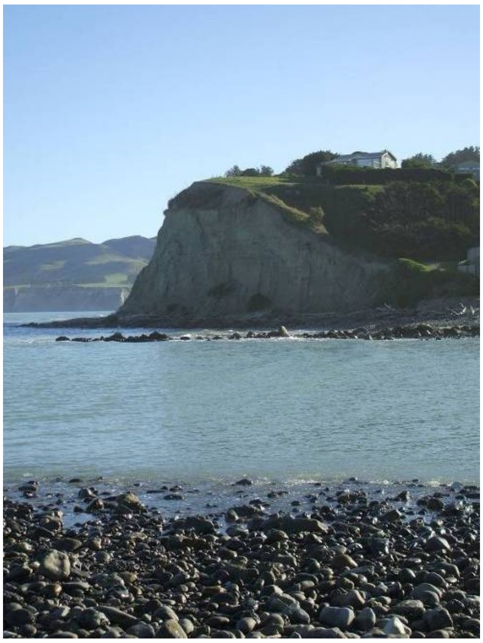


Figure 2.9 Looking southwest towards the cliffs. Motunau River mouth in the foreground (photograph taken 2009).

The erosion of coastal cliffs represents a large source of sand to the sediment budget of the surrounding beaches. There is a complex relationship between rates of cliff collapse and the sediment levels on neighbouring beaches (Ming Shih and Komar, 1994). The morphology of coastal zones and their sedimentary sequences are sensitive to a wide variety of local factors as well as to sea level change (Jennings and Smyth, 1987; Cooper and Pilkey, 2004; Cooper and Navas, 2004; Gabites, 2006).

The erosion of coastal cliffs is the result of the combined influences of historic and contemporary processes. For example, on the North Yorkshire coast, England, the resilient cliffs are thought to be the result of current erosional processes rather than a relic landform reflecting Pleistocene influences (Lim et al., 2009). In East Sussex, England, evidence for the limited chalk cliff erosion during the Holocene lies in the preservation of a Pleistocene beach, indicating more recent rates of erosion (Jennings and Smyth, 1987). Motunau Beach also exhibits features which indicate that the coastline has been exposed to periodic erosional sequences as a result of fluctuations in rising and falling sea levels. These features will be discussed in more detail in Chapter Three.

2.2.1 Section Summary

- 23 % of New Zealand’s coastline contains coastal cliffs.
- Degradation of coastal cliffs is due to the combined efforts of wave attack, sub-aerial weathering, and human manipulation.
- There are regional variations in the rate and volumes of cliff collapse.
- The rate of cliff collapse is dependent upon the strength of the cliff material.
- Closely linked to the rate of regional sea level rise.
- The current morphology is the combination of historic and contemporary processes.

2.3 Sand Beach Erosion and Accretion

70 % of sandy beaches around the world are recessional (Zhang et al., 2004; Cai et al., 2009). When the transfer of sand from the beach to deep water exceeds the rate of sand transfer from the beach to dunes, coastal retreat of sand beaches occurs (Shulmeister and Kirk, 1997; Zhang et al., 2004; Pritchard and Hogg, 2005; van Rijn, 2009). The three primary causes for the retreat of sand beaches are a rise in global sea level, a changing storm climate, and human interference (Zhang et al., 2004). These three causes of sand beach loss alter the sediment supply rates and quantities to a

shoreline. It is because of these factors that the most responsive domain of a coastal zone is that of sandy beaches (Short and Hesp, 1982).

2.3.1 The role of relative sea level rise on sand beach morphology

There are two time-scales of coastal erosion. Long-term erosion is the chronic or progressive change in the position of the shoreline induced by events such as sea level rise, the diversion of rivers, and changes in the coastal sediment budget. Short-term erosion is the result of storm events and is not associated with permanent change of a shoreline. However, short-term erosion can bring about large amounts of destruction (Cai et al., 2009).

When relative sea level rise is at a slower rate sediment is transferred from the offshore towards the nearshore, thus allowing shoreward reworking of deposits and the development of depositional features at the shoreline, such as dune systems (Jennings and Smyth, 1987). This process is similar to the effects of sea level rise on a bevelled cliff. During sea level stand stills these features develop and then begin to erode again when sea level rise is reactivated. Overtopping of dune systems and sand beaches by large waves can lead to the degradation of a sand beach system.

The three main reasons for a higher wave run-up onto sand beaches include larger waves, increased run-up height, and a rise in sea level (Tanner, 1995). Smaller-scale sea level variations can result from El Nino and the passage of offshore hurricanes (Tanner, 1995). The affects of the El Nino-Southern Oscillation (ENSO) are evident along the west-coast of South America, having the ability to warm surface waters in the region and raise sea level by 20 to 25 cm offshore, and 35 to 40 cm along the coast (Tanner, 1995). These periodic fluctuations in sea level have serious implications in terms of erosion on low gradient sand beaches. If a significant sized El Nino, in terms of rainfall, occurs after a large earthquake then sediment transport to the coast via rivers is rapid (McFadgen and Goff, 2005). ENSO is a significant driver of geomorphic change (Goff et al., 2008). In New Zealand three phases of natural climate variation, as a result of ENSO, have been identified. A positive phase occurred between 1922 and 1944, a negative phase between 1946 and 1977, and another positive phase between 1978 and 1998. Positive phases are associated with cooler temperatures and wetter summers in the southeast of the South Island along with wetter winters in the north of the South Island. Negative phases can be associated with increased temperatures across New Zealand. It is during the switching of these phases that periods of faster sea level rise are experienced (O'Donnell, 2007). At Motunau Beach local residents refer to the beach erosion increasing around the 1950s. One possible explanation could be the switching between positive and negative phases of El Nino during 1944 and 1946. This switching would have seen a rise in sea level, by how much is uncertain. Higher wave run up as a result would have seen greater wave energy at the base of the cliffs and higher up onto the dune system at Sandy Bay.

2.3.2 Role of storms on beach morphology

Low gradient, wide sand beaches are characterised by a low flow disturbance and a potential for the greatest sand transport at low tide. These features favour sand dune development (Short and Hesp, 1982). Sand dunes form from the accumulation of sand swept by wind off the berm and in a landward direction. Accumulations of sands can occur from a renewed rate of wind erosion of existing stabilised dunes. Changes in wave energy and changes in sediment supply from rivers can directly influence sediment availability at the shoreline. This process can result in fluctuating dune building phases (Hawke and McConchie, 2006).

The higher energy and turbulence associated with storm waves can infiltrate deeper into beach sediment resulting in enhanced rates of erosion. It is the lower turbulence swell waves that return the eroded sediments back towards the shoreline (Carter et al., 1987; Cooper and Pilkey, 2004; van Rijn, 2009). The greatest effects of wave energy on sandy beaches occur when the dominant wind direction and the angle of wave approach are directed onshore (Morton and Sallenger, 2003). This encourages a higher wave energy which in turn means more turbulence and sediment suspension along the shoreline. A natural asymmetry occurs between the rate of processes of erosion and deposition. This means that a few minutes of erosion has the potential to remove several weeks of deposition (McCave, 2007).

The processes of swash and backwash are responsible for depositing sand on the beach during calm weather conditions. The swash moves up the beach until wave energy is dissipated into the sand, depositing material. The backwash moves sediment seaward from the beach. In calm weather conditions there is usually a net gain in sediment from the swash process. If there is longshore transport in the area then it is the swash and backwash that is responsible for moving sediment downdrift along the beach face. Currents transport finer material in the nearshore environment (Ming Shih and Komar, 1994; Tanner, 1995; Pritchard and Hogg, 2005; van Rijn, 2009).

The hydraulic variables that drive the morphological responses of a sand beach depend upon the wave climate and the sediment. Finer sediments can be tightly packed which means less water percolation into the sediment occurs, and less wave energy dissipation occurs. This occurrence is also supported by Vessey (2003) during her study of Gore Bay which is another popular beach system north of Motunau Beach. Due to the tight packing of finer sediments the level of mobile sediment in the backwash is greater due to the greater velocity. Once sediments have been deposited on a beach, wind, waves, and tidal processes interact to rework and redistribute this sediment. Another phenomenon that can cause fluctuations in the sediment levels of sandy beach systems is the offshore passage of hurricanes. In east Texas, USA, hurricanes caused no significant onshore waves, surf, or swash; therefore, there was a decrease in wave run-up height onto sand beaches. This resulted in an increased rate of aggradations along sandy coasts (Tanner, 1995). Due to Motunau Beach’s position on the east coast of the South Island offshore hurricanes pose little threat to the integrity of the beach system. This is because of New Zealand’s position in the South Pacific Ocean, where hurricanes have little effect. Furthermore, the likelihood of the dune systems along the Motunau promontory being overtopped and degraded by large storm waves is also minimal due to the height of the back beach and the presence of cliffs. The presence of the shallow nearshore also restricts wave heights further decreasing the likelihood of storm wave overtopping.

2.3.3 Morphological controls on sand beach morphology

Every sandy beach environment has its limits or boundaries of the control volume. For example, the landward and the seaward limits of sediment affecting the nourishment of the shoreline (Everts, 1985). In Motunau Beach, Sandy Bay is backed by historic sea cliffs. This means that the extent of the dune system is horizontally restricted by both the high tide level of the sea as well as the base of the cliffs. Erosion of shoreline sediments to offshore sand bars where sediment is stored can both reduce as well as redistribute wave energy at the shoreline (Carter et al., 1987). One mechanism for the movement of material offshore is nearshore current gyres. These gyres can occur when longshore currents, carrying sediment, meet promontories or headlands. The headland presents an obstruction to the path of flow therefore acts as a ramp to inject sediments into deeper waters. This process has been recorded at Cape Gris Nez, France (Sedrati and Antony, 2007). This process also occurs at Kilmachael Point on the east coast of Ireland (Carter et al., 1987). Headlands and promontories can also act as stable points controlling the long-term evolution of the shoreline (Carter et al., 1987; Sedrati and Antony, 2007). For example, they can restrict the amount of sand beach loss, sheltering beaches from storms. Headlands as well as river mouths can act as obstacles to longshore drift and sediment transport. Motunau Beach promontory could potentially act as a ramp that injects the northward moving net drift into deeper waters (Figure 2.10). At Motunau there is a net northward ocean drift due to the way the southerly swell from southwest New Zealand refracts up the east coast of the South Island (Gorman, 2003a/b). At Motunau this net northward sediment potentially meets the promontory and is injected offshore, or it is deposited upstream into the Motunau River mouth, or it is deposited in the pocket beach to the west of the cliffs in Sandy Bay. This process of sediment transport at Motunau Beach has received very little or no attention in the past. To take the understanding of the coastal processes to the next level in the management of this area there needs to be an understanding of what this sediment is doing once it meets the Motunau promontory and where it goes. Is this sediment being injected offshore into deep water canyons where it is being permanently stored? Or is the sediment being stored closer to the shoreline on sand bars, to be brought back onshore during swell conditions?

Figure 2.10 a) image of Motunau Beach promontory. Note the large plume of sediment surrounding the river mouth and Motunau Island (Google Earth, 2009). b) Image of Motunau Beach promontory. Note the plume of sediment surrounding the river mouth and Motunau Island (Ecan, 2009).

In the lee of a shallow continental shelf and nearshore zone in South Australia, low energy reflective beaches receive 25 to 40 % of the deep water wave energy. This is because the shallow near shore contours dissipate the wave's energy prior to it reaching the shoreline (Short and Hesp, 1982). The Sandy Bay beach system at Motunau is also a dissipative environment due to the low angle of the beach. It would appear that the southerly wave component contributes the greatest amount of deep water wave energy to the shoreline. However, this process is potentially complicated by Motunau Island which alters the form and amount of wave energy received at the shoreline. These variations in wave energy, sediment availability, and vegetation cover can result in variable dune morphologies and sand beach profiles (Short and Hesp, 1982).

2.3.4 Anthropogenic interference

The greatest variations in beach profiles and beach volume along Pegasus Bay, New Zealand, occurred around sand spit tips, river mouths, and sites that have not been developed immediately behind the beach (Gabites, 2006). This occurs because human interference restricts the natural fluctuations and adjustments in beach morphology, and affects the rate at which the hydraulic variables, such as alongshore currents and tidal processes distribute sediments along a beach. External influences upon a sand beach can result in large spatial and temporal variations in morphology (Zhang et al., 2004).

There is a trend in the development of coastal dune systems worldwide during periods of high sand supply (Goff et al., 2008). These sand supply periods can be linked to climatic events such as storms, marine transgressions, as well as to anthropogenic land clearance or tectonic events. These processes reinvigorate catchment sediment supplies (Barrell, 1989; Masselink and Hughes, 2003; Ewers et al., 2006; Goff et al., 2008; Hart et al., 2008).

There are two distinct periods of human colonisation in New Zealand; Maori settled in New Zealand around 1250 AD, and Europeans arrived in the early-mid 19th century. Both periods were associated with large-scale vegetation clearance. Dune ridge formations can be dated to these times (Goff et al., 2008). Large-scale forest clearance began on the Canterbury plains in the 1870s and continued up until the mid 20th century (Ewers et al., 2006; Orpin et al., 2006). However, in Otaki, New Zealand, episodes of increased sediment supply to the coast is the result of erosion induced by climatic factors, such as high rainfall events, rather than human induced land change. Furthermore, the position of the Otaki River mouth has had a substantial influence on beach character and input of sediment suitable for sand dune formation (Hawke and

McConchie, 2006). In the southeast of the South Island, New Zealand from approximately 1863 onwards there was a marked growth in sand dune height along the Otago coastline. The cause was the expansion of gold mining activities in the Otago Goldfields, which released large quantities of sand and sediment into the Clutha River. This large fluctuation of sediment at the coast resulted in deposition on the downdrift beaches in the form of sand dunes (Goff et al., 2008).

Sandy Bay is situated adjacent to the mouth of the Motunau River. A possible scenario for the accretion of the Sandy Bay beach could be related to early settlement patterns in the area, of both the Maori and European, and large sediment fluxes in the river catchment associated with the vegetation clearance. As farming practices changed there could have been a decrease in sediment levels and therefore erosion of the beach system commenced. Sediment fluxes in the river systems eventually reach the coast and have the ability to form fine sediment sand beaches. The rate at which this occurs depends on catchment activities, for example forestry and farming. If these processes of land clearance continue for a duration we would expect to see a coast that is rapidly moving seaward (Goff et al., 2008). However, observations also show that this eroded material can accumulate close to the eroding area and not reach the coast at all (Liquete et al., 2009). In New Zealand the transitional phase between clearing vegetation and establishing a desired farming practise is responsible for high suspended sediment levels in the waterways (Goff et al., 2008). In Catalonia, northeast Spain, human activities have moved ten times the amount of sediment than natural processes (Goff et al., 2008). This is also supported by Jennings and Smyth (1987) in East Sussex, England, where iron-age forest clearance has resulted in alteration of river systems as well as coastal sedimentation patterns. This relationship between forest clearance and accelerated erosion of land in the catchment has also been seen in the Raukumara Ranges, North Island, New Zealand (Orpin et al., 2006).

A combination of anthropogenic interference and sea level fluctuations during the current interglacial period has meant there have been large variations in amounts of terrestrial sediment supplied to the coast. Despite the natural and human inputs to the coast, large areas of sand beach continue to erode and lose material, for example, the East Sussex coast, England. Potentially this is due to the decline in offshore supplies of sediment (Jennings and Smyth, 1987). This is expected to become increasingly severe due to predicted rise in sea-level which poses problems for coastal settlements and property.

2.3.5 Section Summary

- 70 % of sand beaches worldwide are recessional.
- Three primary causes; global sea level rise, changing storm climate, human interference.
- Two time scales of erosion; long-term, the progressive change in shoreline position. Short-term, storm events.
- Morphology of sand beaches is affected by wave energy and sediment supply.
- Humans restrict the natural fluctuations in beach morphology.

2.4 River Mouth Dynamics

After the last glacial maximum approximately 18,000 yr BP there was a change to postglacial river incision on a global scale which caused large-scale river dynamics and climate changes (Marden et al., 2008). Sea level began to rise with varying rates of progression and there was a major sediment fluctuation in the coastal waters off New Zealand. Sea level continued to rise up until 6 to 5,000 yr BP resulted in the shortening of river courses and moved the aggradation point upstream (Starkel, 1995).

2.4.1 River bar morphology

When river water meets the sea it will drop its sediment load at the junction of deeper water forming a bar (Wright et al., 1980; Fielding et al., 2005; van Rijn, 2009). The behaviour of the river discharge as it enters the ocean depends on the river velocity, the slope of the sea bed at the river mouth, and the density of the water column. These three features interact to determine the form of the river mouth deposit (Masselink and Hughes, 2003). When river flow enters the sea at the river mouth it can take a variety of forms (Figure 2.11). These forms depend upon the amount of sediment being carried by the river, which in turn affects the rates of deposition at the river mouth. Upon entering the ocean the processes of tides and waves interact to shape the form of the deposit. The three main types of river mouth deposit are; a buoyant plume, an axial jet, or a planar jet (Masselink and Hughes, 2003). River bars and deltas at the mouth of rivers also modify current directions and flows of longshore sediment transport (Ozsoy and Unluata, 1982). The bottom friction or bed roughness in the nearshore zone can retard discharge flow from a river mouth. This has implications for the expansion of the sediment plume and flow jets.

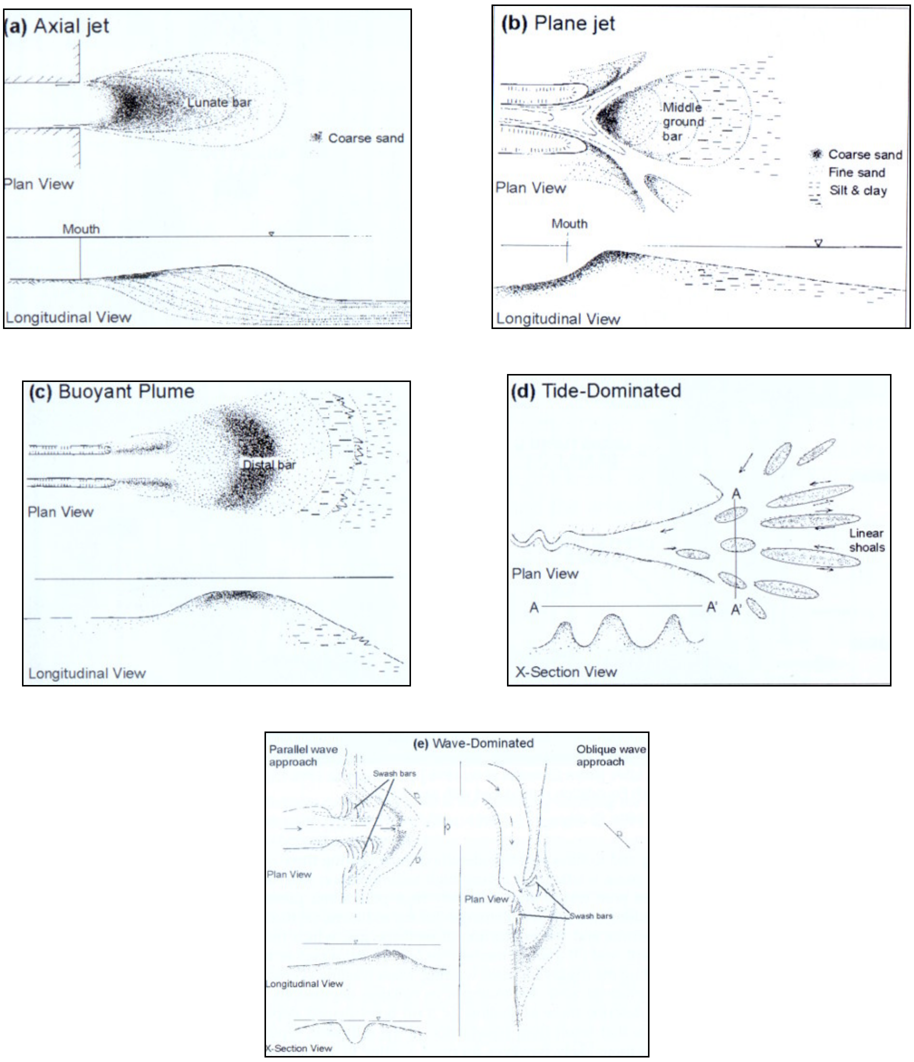


Figure 2.11 Forms of river bar deposit (Masselink and Hughes, 2003). It would seem that the most likely deposits at the Motunau River mouth would be similar to a, b, and c due to the confined nature of the Motunau River mouth.

On sandy coasts, river mouth bar deposits consist of medium to very coarse grained sediments. As you progress seawards these sediments change to medium grains, passing seaward even further to interbedded mud and muddy sands (Fielding et al., 2005). These bar deposits often form over a scale of tens of years and their morphology is mostly dependent on high-magnitude and short-duration fluvial events (Fielding et al., 2005). The formation of a river mouth bar is also influenced by periodic variations in river flow. After a period of runoff the river bar will deposit inland until the crest reaches the high tide level or just below it. If the bar remains unaltered by human influence or large flood events, a beach will then begin to grow on the seaward side of the bar. This beach is reworked by the wind and the waves and the coarser fraction of sediments are buried by finer sands (Fielding et al., 2005).

It is the high yield rivers around the world that contribute the majority of terrestrial sediment to the world's oceans, although often their dispersal patterns are not well understood. Smaller rivers tend to exhibit a more event dominated sediment transport, for example the Eel River, California, where floods discharge river flows offshore which last a day or less (Orpin et al., 2006). In other words these occurrences are low frequency and high magnitude events, not unlike the flow regime of the Motunau River. The Motunau River mouth bar (Figure 2.12) poses a natural hazard to fisheries access to the area. For this reason it has been heavily modified in the past in order to maintain the use of the river mouth. Due to the constant manipulation of the bar and lower reaches of the river mouth, the natural processes of avulsion and sediment depositions have been changed. At the time Figure 2.12 was taken in July 2009, the section of bar that was exposed consisted of coarse gravel, similar to that found on the neighbouring rock platforms. According to local fishermen, prior to the large flood in August 2008, the bar and river mouth was congested with coarse sand similar to that found on Sandy Bay.

Figure 2.12 Photograph taken from the river mouth looking south towards Motunau Island. In the foreground the Motunau River mouth bar is semi exposed (July 2009).

2.4.2 River sediment transport

The forms of river deposits are also dependent upon the level of sediment in the water. Hypopycnal river flows occur when river water is carrying less sediment than sea water. The river water will float above the sea water towards the sea. When fresh river water is laden with sediment it is denser than sea water and will travel seaward along the river bed below the sea water; this is called hyperpycnal river flow conditions (Masselink and Hughes, 2003). At Motunau Beach it is common to see variations of both hypopycnal and hyperpycnal flow conditions in the lower reaches of a river system. These conditions can occur both in combination with each other or separately. However, is most easily visible under calm river flow conditions. That is when river flows are not large enough to cause a dominance of flow in one direction (Figure 2.13). Low river flow, along with the ebb and flood of the tide, influence the level at which the river water enters the sea water column.

Figure 2.13 A plume of sediment drifts upstream on the flood tide in the lower reaches of the Motunau River (photograph taken 2008).

A reduction in river discharge at the river mouth enables sediment laden sea water to encroach further upstream. This results in the deposition of silts and fine sand deposits in the mouth of the river. On the flood tide, sediment laden sea water loses its velocity as it travels up river, depositing material within the river channel. On the ebb tide the river cannot remove the material seaward, resulting in a net gain of sediment at the mouth of the river (Chandramohan et al., 2001). River mouth closure is not only influenced by the level of sediment delivered to the mouth by fluvial processes, but also, longshore drift and onshore sediment transport. Littoral processes can deliver sediment to the river mouth or bar deposit. The sediment is then transported upstream of the river by wave action and the flood tide (Wright et al., 1980; Ranasinghe and Pattiaratchi 1999; Davidson et al., 2008).

Rainfall events can lead to floods that carry large volumes of sediment rapidly to the coast. This can take the form of either dissolved, suspended, or traction load (Fielding et al., 2005). Changes to the form of the river mouth can often occur in response to landslides in the catchment, changes in forest cover, aggrading rivers, tectonic uplift, and coastal margin instability (Orpin et al., 2006). As a natural hydraulic response to variable river flows there are often large fluctuations in the area of the river mouth. Natural adjustments in channel morphology, in response to changing river flow volumes, can influence the shape and form of the discharge plume and bar (Jennings and Smyth, 1987).

2.4.3 Channel morphology

There are both internal and external factors that lead to hydraulic adjustments of the river mouth. Following channel disturbance a period of progressive readjustment towards a new stable morphology occurs (Park, 1995). The Motunau River mouth shows rapid adjustment to variations in river flow and other variables as indicated by the historical channel profiles in Figure 2.14.

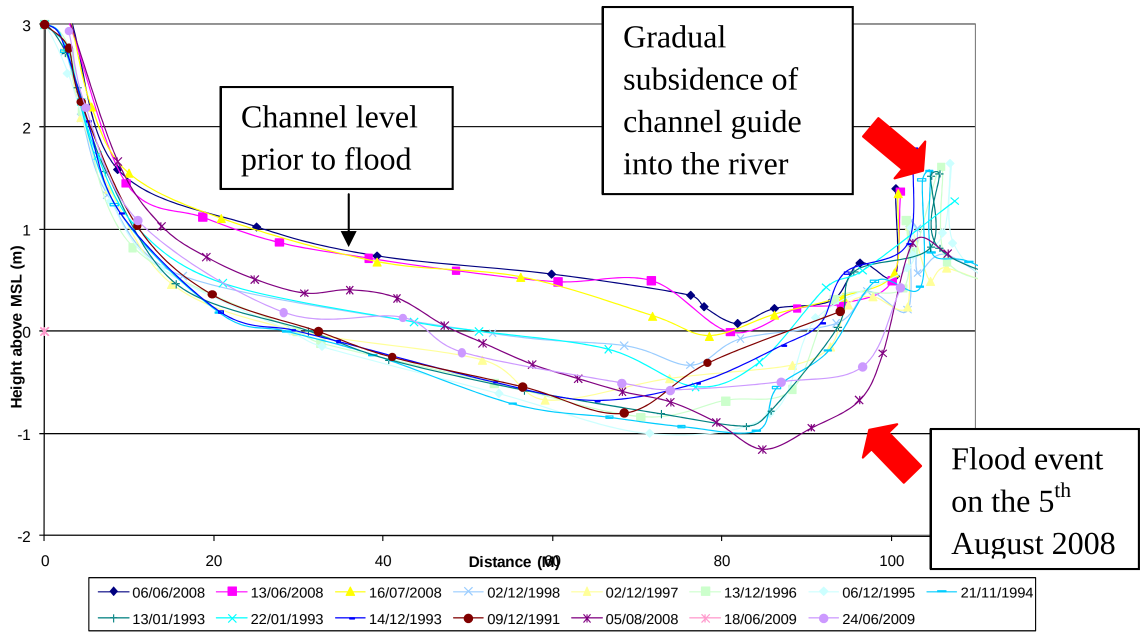


Figure 2.14 ECAN H2554 shore profile at the mouth of the Motunau River. The older profiles exhibit a range of channel forms in response to the variable river flows. Left hand side represents the edge of the car park area, whereas the right hand side of the profile represents the concrete block channel guide. Historical profile information sourced from ECan 2009a.

Instability and change of river cross-sections occur over both short and long-term time scales. Short-term channel forms are more accurately predicted. Channel forms over long-term geological timescales are less predictable. This is due to climatic variables, such as global warming, which interact with the relief and geology of an area (Jia and Hinwood, 2009). The variable rates of change of a river profile are dependent upon the sediment supply and the river flow dynamics, for example velocity (Madej et al., 2009).

Wave dominated river mouths are the most responsive form of river mouth systems. This type of river mouth will exhibit rapid morphological changes due to the interactions of shallow water, waves, and tides (Wright et al., 1980; Bertin et al., 2009). Furthermore, deposition of sediments in these shallow breaker zones results in turbulent bed friction and loosely consolidated river deposits. This combination of factors results in an increased lateral spreading of the river discharge due to the effects of waves. This means that the bar and position of the main outlet under these conditions are unstable (Wright et al., 1980). From initial observations it would appear the Motunau River mouth is not dissimilar to this scenario.

Littoral drift and the amount of sediment carried by a river will cause rivers to migrate and switch. Switching is a natural process that finds the shortest and most efficient route to the sea in response to variable water levels and sediment loads (Shulmeister and Kirk, 1997; Masselink and Hughes, 2003; Mateo and Siringan, 2007). Switching direction will favour towards the direction of the dominant nearshore current. The Burdekin River, for example, owes its river mouth position to short-duration and high-magnitude river discharge events rather than to the smaller-scale processes of tidal and wave reworking (Fielding et al., 2005). It also appears the Motunau River owes its position to these high-magnitude and short-duration events. Where the mouth of a river is confined by channel guides or rock groins, evidence of the undercutting of these structures by the river is an indication of channel switching or wanting to change its orientation. It is during and after large floods that this process is often initiated (Shulmeister and Kirk, 1997). In August 2008 the Motunau River experienced a short-duration and high-magnitude flood event which lowered the channel level at the river mouth by approximately 1 m (Figure 2.14). Profiles revealed that after the flood the river had shifted to a position that undermined the precast concrete block channel guide on the true left of the river. The concrete blocks subsided into the channel. When these 2008 profiles were compared to historical profiles, which date back as far as 1991, a gradual subsidence of the blocks into the channel can be seen to be occurring. Furthermore, this can be clearly seen in Figure 2.15. This could potentially be seen as a natural indication that the mouth of the Motunau River does want to avulse, or switch, in a northwards direction. Due to the obstruction posed by the block channel guides this progress is hindered. Rather than spreading out laterally in times of high river flow events, the river is forced to incise down into the bed as seen in Figure 2.15.

Figure 2.15 Subsidence of precast concrete channel guides. Note the elevation difference between the river channel bed and the beach to the right. Photograph taken 26th July 2009 looking upstream from the mouth of the Motunau River.

2.4.4 Section Summary

- River mouths are influenced by sea level rise.
- The form of the river bar deposit is dependent upon the amount of sediment in the river flow.
- The three main forms of river mouth deposits are; buoyant plume, axial jet, planar jet.
- The high-magnitude and short-duration floods are influential in the morphology of river mouth orientation and form.
- River mouths are often characterised by periodic variations in the level of river flows.
- Manipulation by humans affects natural hydraulic adjustments.
- There are both internal and external influences on channel morphology.
- There is a combination of long-term and short-term changes within river mouth dynamics.

2.5 Waves and nearshore transformations

Wind driven ocean waves create nearshore currents and transport sediment. They are the driving force behind morphological change in a coastal environment (Fredsoe and Deigaard, 1992; Masselink and Hughes, 2003). The three most common forms of waves in a beach environment are; breaking waves, broken waves, and reflected waves. Breaking waves can be further divided into spilling, plunging, and surging waves. Spilling waves are associated with gentle gradient beaches, plunging waves with steeper intermediate beaches, and surging waves with steep beaches (Masselink and Hughes, 2003). Characteristics for describing waves include; wave height or the elevation between the trough and crest, wave length or the distance between successive crests or troughs, and the wave period which is the time taken for a wave to travel a distance equal to its wave length (Masselink and Hughes, 2003).

Wind waves form when wind blows over the surface of the ocean, transferring energy from the wind to the water. During the formation of a wave its height will grow exponentially as the square root of energy. The energy of a wave is a function of its length and height. When a wave reaches its limit of steepness ($H/L=1/7$) it will break to form a white cap, usually when wave height is 0.8 times the water depth (Munk and Traylor, 1947; Fredsoe and Deigaard, 1992; Masselink and Hughes, 2003). Strokes Drift is the process of water movement in the direction of wave travel due to the water particle motion. Water particle motion is elliptic in shape in shallow water, travelling forward at the upper part of the orbit and backwards at the bottom of the orbit (Fredsoe and Deigaard, 1992; Masselink and Hughes, 2003). In deep ocean water wave crests do not reach as high due to the absence of the seafloor and the influence on the water particle motion. Wave velocities also remain higher compared to when the orbital motions of the water particle reach a continental shelf, the associated friction changes the form of the wave. In waters that are shallower than less of half a wave length ($d=L/2$), the friction from the bottom causes the wave to lose energy and slow down. This means that the wave length decreases and the wave height increases (Fredsoe and Deigaard, 1992; Flinn, 1997; Masselink and Hughes, 2003).

As a wave enters the shallow water of a coastline the bathymetric contours influence the speed that the wave approaches the shoreline. Important factors determining the influence and effects of the wave form as they approach a shoreline are; the slope of the beach, the steepness of incoming waves, and the direction of wave approach in relation to the angle of the shoreline (Fredsoe and Deigaard, 1992). Wave energy consists of two components; the potential energy and the kinetic energy. This energy is transported in the direction of wave propagation (Fredsoe and Deigaard, 1992). Throughout this thesis this will be referred to as the wave orthogonal. The energy of the wave is dissipated at the shoreline when the wave breaks in the surf zone. The surf zone is the site of the most intense sediment transport. This is due to the high turbulence and shallow water (Fredsoe and Deigaard, 1992).

When a wave approaches a stretch of coastline at an oblique angle the consequent wave breaking will produce a shore-parallel current (Figure 2.16). If the shoreline contains unconsolidated sediments the sediments will be transported. The rate at which this shore transport occurs is dependent upon the angle at which the waves approach the shoreline, for example if the angle of wave approach towards the shore approaches 0˚ then the wave momentum along shore also approaches 0˚. When the wave angle approaches 90˚ then the wave momentum and energy along shore also approaches zero. However, it is between these extremes (45˚) that the alongshore thrust component reaches its maximum (Ashton et al., 2001).

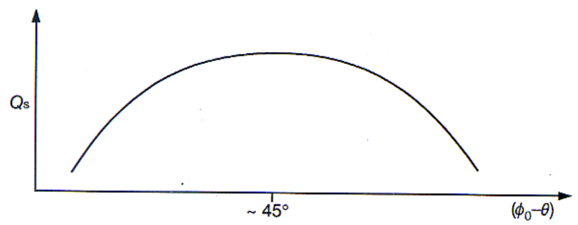


Figure 2.16 Qs is the alongshore sediment flux, a non linear function off the local shoreline angle relative to the wave crests (Ashton et al., 2001, pg 297).

Wave erosion of shoreline sediment is more prominent in storm wave conditions. This is due to the stronger winds and the greater wave energy breaking at the shoreline (Masselink and Hughes, 2003). The cyclical nature of tides controls the water level and the variable heights of wave erosion. Waves are more energetic at any given point on a beach at high tide. This is due to the greater water depths and reduced energy dissipation by the seabed compared to during low tide. For this reason we expect the rate of erosion to increase at high tide and high wave set-ups (Masselink and Hughes, 2003). Tidal flows can also increase wave heights on an open coast when tidal flows are in opposition to the wave approach direction (Hansom et al., 2008).

Waves display variations in form as a result of sediment, water depth, irregular sea floor features, and the size of the fetch (Munk and Traylor, 1947; Fredsoe and Deigaard, 1992; Masselink and Hughes, 2003). Wakes from large vessels can significantly contribute to the wave climate in fetch restricted environments, such as in the lee of offshore islands (Curtiss et al., 2009). Fetch restricted wave processes can be applied at Motunau Beach due to the position of Motunau Island 1 km offshore of the Motunau River mouth. Although there is regular boat traffic in the nearshore zone it is arguable whether the wake from these vessels is posing any significant detriment to shoreline morphology. This is because these vessels are neither large enough nor frequent enough. Motunau is popular with recreational fisheries during weekends and during certain times of the day that optimise water depth for channel access. However, vessels within the lower reaches of the channel may be causing scouring of the channel sides and river mouth bar due to vessel wakes.

The position of Motunau Island is potentially responsible for modifying the height and amount of energy that is received at the shoreline. Although there is often variable wave heights at sea beyond the island it is not uncommon to see breaking waves at the shoreline in the height range of 0.5 to 1.8 m. The nearshore zone, due to the sheltering of the island and the shallower waters, is generally an energy dissipative zone. When southerly wave conditions prevail we would expect to see the most drastic shoreline fluctuations as the sheltering effects of the island are less; therefore, the shoreline receives a higher percentage of deep water wave energy. Motunau Beach is not in the latitudes that frequently get tropical cyclones. Tropical cyclones are said to have a significant effect on wave heights and consequently the morphology of a coast, for example, In 1997 during the passage of Tropical Cyclone Justin, off the coast of Queensland, Australia, the average wave periods rose from 4.0 s to 6.67 s and the average wave heights went from 0.66 m to 2.34 m (Fielding et al., 2005).

2.5.1 Wave Refraction

When the wave particle motion makes contact with the seabed it causes a rotation or bending of the wave crest. This causes the wave to progressively align parallel to the coast as it progresses from deeper water to shallow water. This depth controlled bending of wave crests is known as wave refraction and is fundamental to sediment transport and morphodynamics of a coastal environment (Munk and Traylor, 1947; Masselink and Hughes, 2003). The process of wave refraction redistributes wave energy at the shoreline and along the coast and can alter seafloor features by the accumulation or removal of sediments (Munk and Traylor, 1947; Short and Hesp, 1982). The refraction of waves is complicated by underwater relief features such as submarine canyons, ridges, headlands, bays, and offshore islands (Figure 2.17).

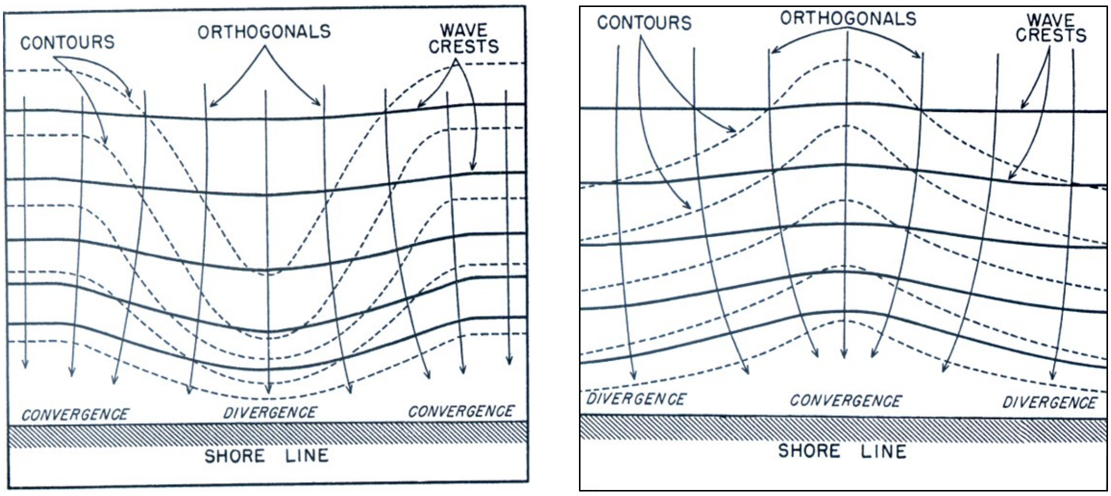


Figure 2.17 Divergent and convergent wave crests as a result of bathymetry (Munk and Traylor, 1947).

Features at the coast that cause the refraction of waves can occur in isolation or interact in a coastal complex. When a complex of features interact, the convergence and divergence of wave crests and wave energy occurs. When refracted waves meet they can be further transformed and bent, altering both the wave direction and wave periods (Munk and Traylor, 1947). The redistribution of wave energy can lead to pockets of concentrated wave energy. This can lead to a natural asymmetry in erosion along a stretch of shoreline. Along Motunau Beach different levels of wave refraction are occurring. Waves are being refracted around Motunau Island into the nearshore zone, and then further refracted across the rock shore platforms and within Sandy Bay (Figure 2.18).

Figure 2.18 a) Wave refraction at Motunau Beach on the rock platform at the base of the coastal cliffs (September, 2009). b) Wave refraction into Sandy Bay (August, 2009).

Offshore islands provide significant shelter to the coast from the deep ocean surface gravity waves (Figure 2.19). The wave energy is either dissipated in the islands surf zone or reflected back out to sea (Ashton et al., 2001). Associated with islands are a series of complex processes which can propagate wave energy into the lee of an island (Pawka et al., 1984; Flinn, 1997). Constructive interference is a process that occurs when two wave trains refract around an island and coincide on the leeward side where they become larger. This often results in rough wave conditions. These constructive waves exhibit unpredictable behaviour and can result in drastic changes in shoreline morphology. The amalgamation of wave trains can also have the opposite effect, whereby the wave lengths (troughs and crests) are out of phase reducing the wave energy. This can result in minimal displacement of the water surface (Masselink and Hughes, 2003).

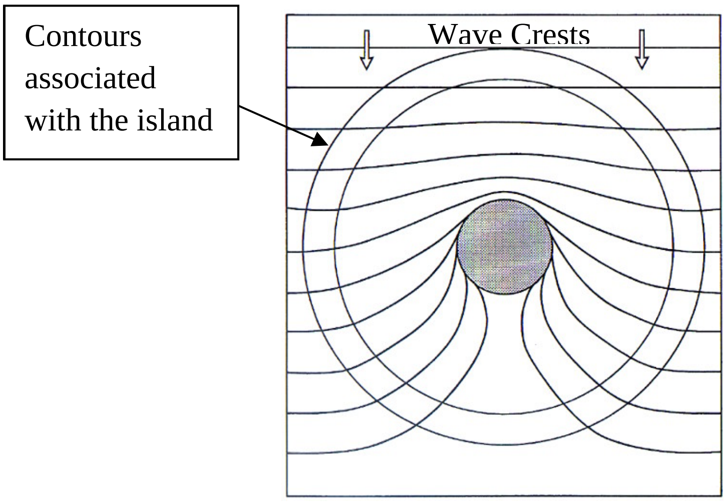


Figure 2.19 Wave refraction around an island. Reflection and diffraction ignored (Flinn, 1997, p 203).

Wave defraction (Figure 2.20) occurs when the wave energy is transferred along a wave crest rather than in the direction of propagation. A shadow zone is created behind an obstacle to the waves, such as an island, causing wave energy to spread into the shadow zone (Muir-Wood and Flemming, 1981; Masselink and Hughes, 2003). This can occur in unison with wave refraction. When a wave refracts around an island the zone where wave crests meet can experience turbulence on the sea floor which suspends sediment. The sediment is then carried shoreward and deposited during the swash as a wave breaks (Flinn, 1997; Pritchard and Hogg, 2005).

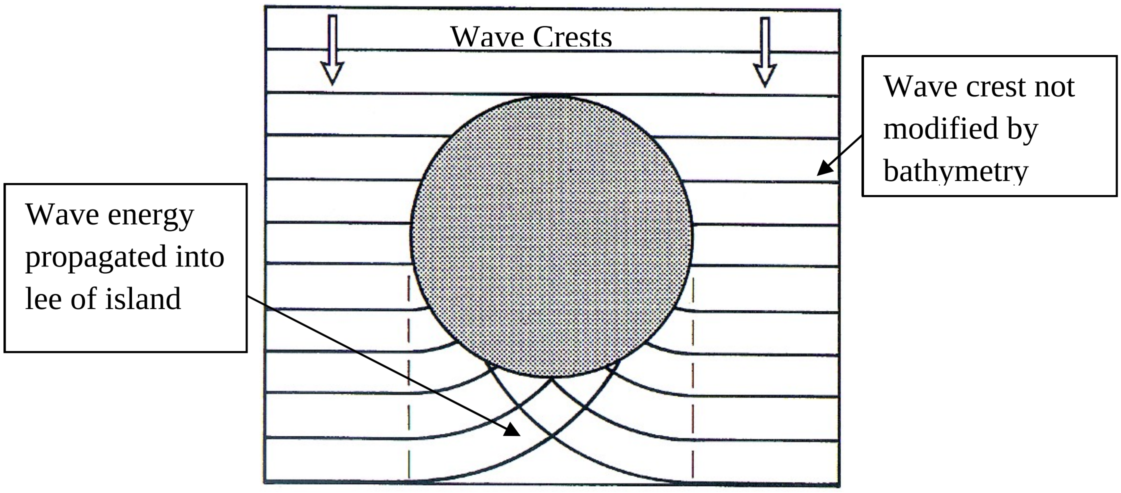


Figure 2.20 Wave defraction around an island. Effects of reflection ignored (Flinn, 1997, p 204).

2.5.2 Bathymetric controls on shoreline morphology

Wave interaction with the seafloor is important in shaping the shoreface. The shape of the bathymetry can influence the level of wave induced upwelling and down-welling of currents along with the speed of gravity flows; or underwater subsidence (Cooper and Pilkey, 2004). Hummocky and irregular seafloors associated with underwater avalanche deposits and the erosion of a delta lobe, are two explanations for an irregular nearshore bathymetry (Fielding et al., 2005; Orpin et al., 2006). Although the relevance of avalanche deposits in the Motunau nearshore zone is questionable due to the low angle, there is a potential for river mouth deposits that play an important role in shaping nearshore bathymetry at Motunau. Bathymetric controls can dictate the direction of wave energy to the shoreline. For example, both bathymetric depressions and headlands can steer and focus currents and therefore sediment transport (Storlazzi and Field, 2000). The shoreline then responds to the erratic wave energies via variations in the areas of sediment erosion and accretion. These variable zones of erosion and accretion can also occur within the bathymetry of the nearshore zone (Fredsoe and Deigaard, 1992; Vessey, 2003; Frihy et al., 2008; Cooper and Navas, 2009). On Dauphin Island, South Carolina, zones of dune over-wash and breaching of sandy beaches is caused by bathymetric wave focussing (Morton and Sallenger, 2003). This example is relevant to Motunau Beach as it suggests a possible explanation, one that needs further examination, for the accelerated rate of cliff retreat and sand beach loss. A flat nearshore that lacks relief features in the bathymetry can facilitate the shoreward movement of sediment and the development of sand beaches and dune systems (Jennings and Smyth, 1987). Areas of sediment accumulation, or sinks, can be defined as semi-permanent locations for sediment, and include sand beaches or offshore deposits (Chandramohan et al., 2001). For example, off the Poverty coast, North Island, New Zealand, the Paritu Trough and lower slope basin has accumulated large amounts of terrigenous sediment (Orpin et al., 2006). Due to the lack of detailed hydrographic investigations at Motunau Beach there is little knowledge on the areas of sediment sources and sediment sinks. A valuable link that is missing in the coastal process understanding at Motunau Beach is the passage of the sediment once it has been eroded from the shoreline. Is this sediment being ejected offshore and accumulated in troughs like that of the Paritu Trough? Or is the sediment being accumulated closer to shore? These are some of the questions that could be answered if a hydrographic survey of the Motunau area could be carried out successfully. However, measuring and recording nearshore bathymetry can be very dangerous and expensive (Nicholls and Taber, 2009). Modelling the role of bathymetry and waves on shoreline morphology requires corresponding observations and recording of winds, tides, wave heights, and flow velocities (Plant et al., 2009). Understanding the mechanisms leading to offshore deposits of sediment is critical in understanding sediment dispersal along a particular stretch of coast (Orpin et al., 2006).

2.5.3 Section Summary

- Waves are the driving force behind morphological change.
- The bathymetry affects the speed of waves and the angle of wave approach.
- Wave energy is transferred in the direction of propagation (wave orthogonals).
    - Bathymetry can focus and dissipate wave energy
    - Bathymetry can facilitate the accumulation and dispersal of sediment from the nearshore.
- Shoreline erosion is more prominent during storm wave conditions.
- The refraction of waves redistributes wave energy along the shoreline.

2.6 Chapter Summary

Chapter Two has introduced an array of national and international examples of the processes that are occurring at Motunau Beach, in doing so, establishing a broad knowledge base of the processes in which to build from. This chapter outlined in detail four of the key coastal processes which will continue to emerge throughout this thesis. Furthermore this chapter has reinforced that the processes that are occurring around Motunau Beach are not unique, both nationally and internationally; however, the combination of processes and they way they are interacting within such a confined space highlights the distinctive nature of the Motunau promontory.

Chapter Three

The Motunau Beach Coastal Environment

3.1 Introduction

This chapter identifies the variety of larger-scale morphological controls on the coastal processes at Motunau Beach (Figure 3.1). In doing so answering the first of the research questions; what are the processes causing cliff erosion at Motunau? This chapter outlines the geological characteristics of the Motunau area. Sections 3.2 and 3.3 describe the geological background which influences the local geomorphology and rates of morphological change. Section 3.4 reviews previous research into the physical processes of change at Motunau. Section 3.5 outlines the different groups of people involved in the use of the promontory.

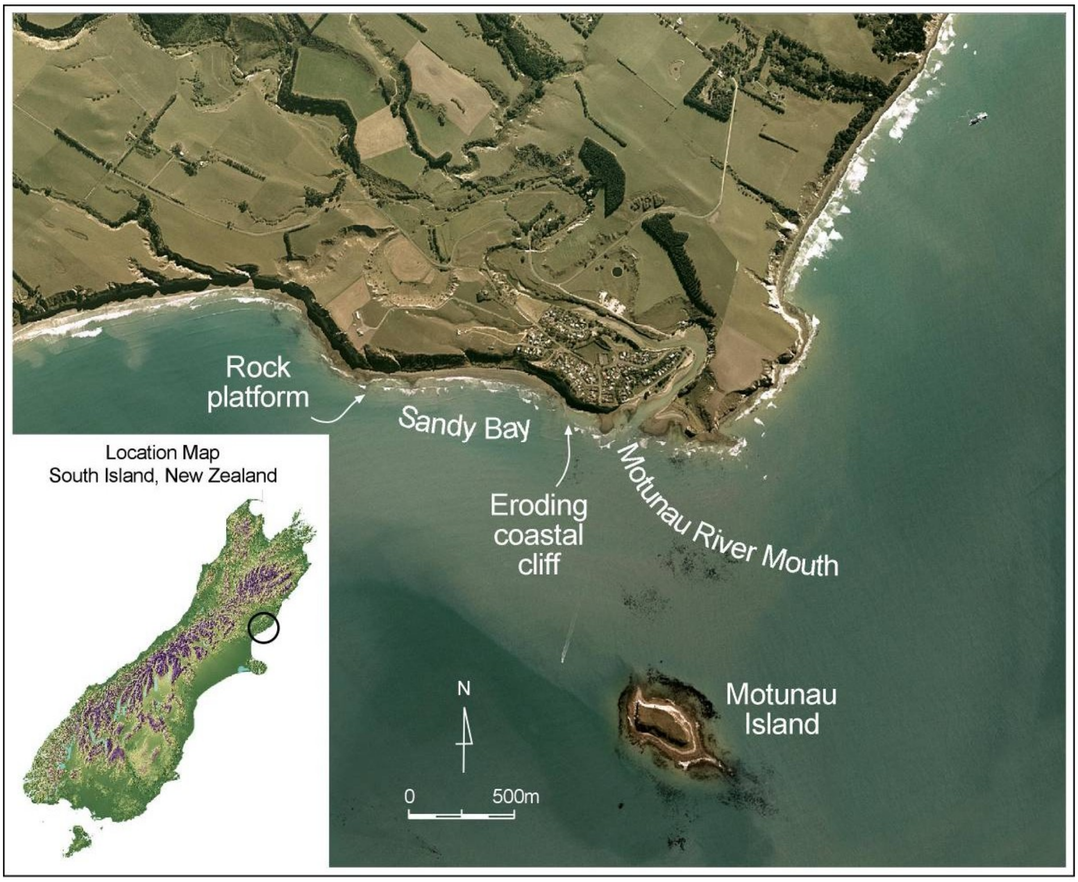


Figure 3.1 Location of Motunau Beach and the interacting coastal processes which are of interest for this study. Features have been superimposed on the 2004 aerial photograph (Linz, 2009).

3.2 Geological Background

The Motunau promontory is a remnant of the Motunau Plain (Figure 3.2). This plain was formerly an extensive coastal plain formed by retreating sea level approximately 80,000 yr BP prior to the last glaciation (Jobberns and King, 1932). The steeper slopes that are at the landward edge of the Motunau coastal plain (Figure 3.3) were once sea cliffs during the last interglacial period 125 to 80,000 yr BP. The base of these historic sea cliffs now lies approximately 90 to 106 m above current sea level (Jobberns and King, 1932).

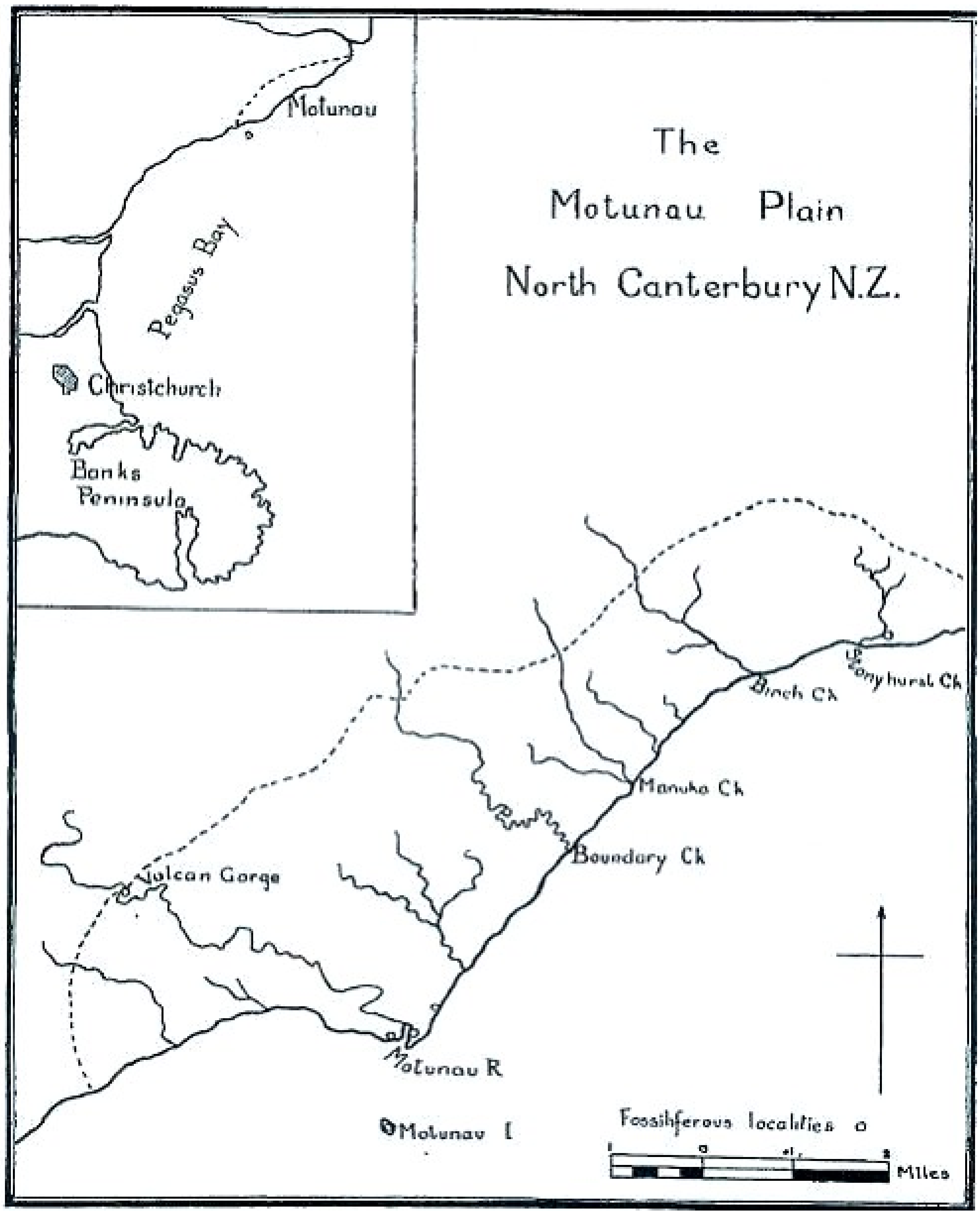


Figure 3.2 Location of the Motunau coastal plain (Jobberns and King, 1933).

At the widest point of the Motunau coastal plain is the Motunau Beach promontory. The promontory is approximately 2.5 km in length and includes Motunau Island, which lies 1 km offshore from the Motunau River mouth. The promontory and the Motunau coastal plain consist of Greta siltstones of Pliocene (5.332 to 2.588 ma) to early Quaternary (2.588 ma to present) age. As sea level retreated during the last glaciation (Figure 3.3) the plain was overlain by marine deposits and further mantled by fluvial sediments and loess. Loess is the yellow-brown sandy silt deposited by the wind (R.W. Morris and Associates, 1987; Barrell, 1989; Lumsden and Kirk, 1991; Marshall, 2005; Bell Geoconsulting Limited, 2008). This loess material has been derived from the last glaciations with an age of 20 to 25,000 yr BP (Bell Geoconsulting Limited, 2008).

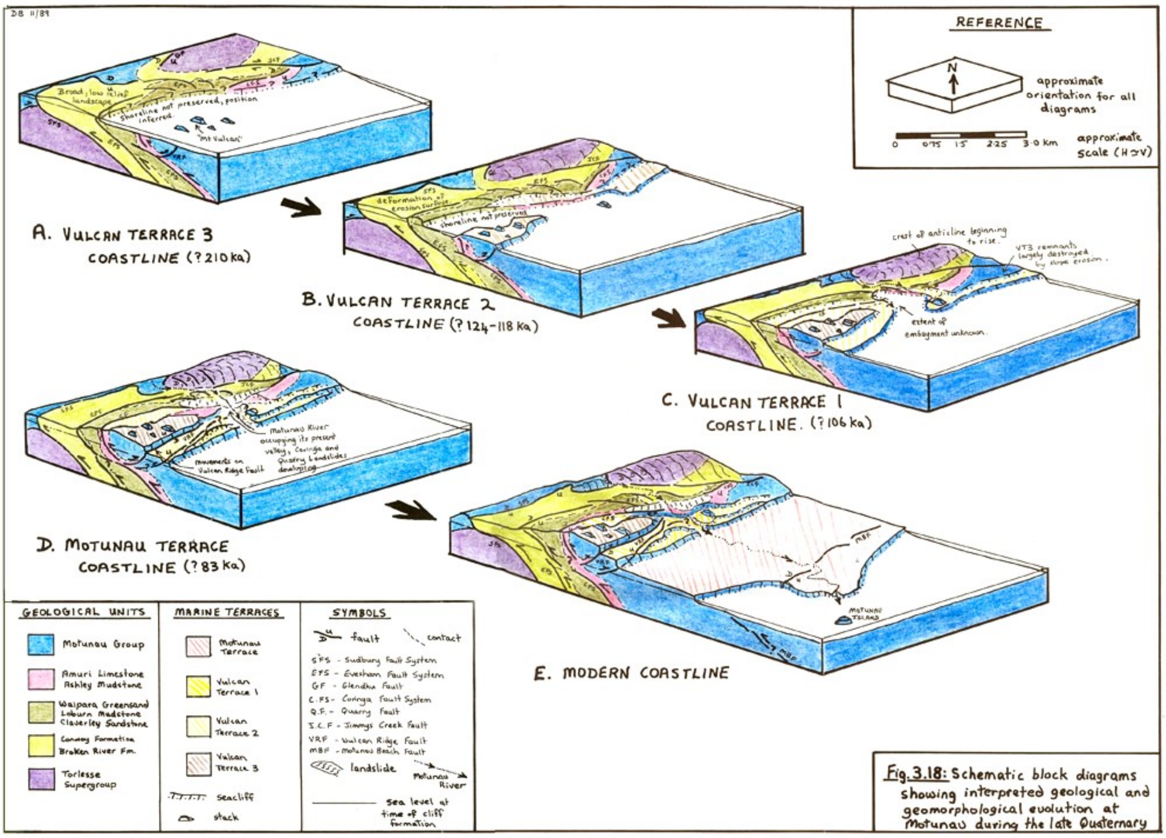


Figure 3.3 Formation of the Motunau coastal plain (Barrell, 1989).

At its lowest, roughly 20,000 yr BP, the sea level was approximately 130 m below present levels and 50 km seaward (Kirk, 1979). As the sea level has advanced erosion of the Motunau plain has been commenced with fluctuating rates of advance. The current Holocene epoch (11.700 yr BP to present) represents a newer interglacial period. During the Holocene the sea level has risen, reaching its current position around 5,000 yr BP (Herzer and Lewis, 1979; R.W. Morris, 1987; Lumsden and Kirk, 1991). The current average rate of global sea level rise is 1.8 mm yr^{-1}. Since the 1900s there has been a rise of 0.2 m (Bell et al., 2001), sea level is expected to continue to rise over the next century within the range of 5 to 10 mm yr^{-1} (Warrick and Oerlemans, 1990).

The Motunau Beach fault, identified by Barrell (1989), dissects the Motunau coastal plain and is responsible for the uplifting of the seaward edge of the plain where the erosion of coastal cliffs is occurring (Figure 3.4). Suggate (2004) suggests that north of Christchurch tectonic warping has affected all marine shorelines. This uplifting of the seaward edge has had significant implications for the Motunau River system and its sinuosity downstream of the fault. Across the plains width, of approximately 1.2 km, there are temporal and spatial variations in rates of tilt and uplift. This is roughly 0.66 mm yr^{-1} at the coast and increases to approximately 1.5 mm yr^{-1} at the seaward range (Barrell, 1989). It is often hard to distinguish the direct tectonic influences on coastal morphology due to possible delayed after-effects (McFadgen and Goff, 2005).

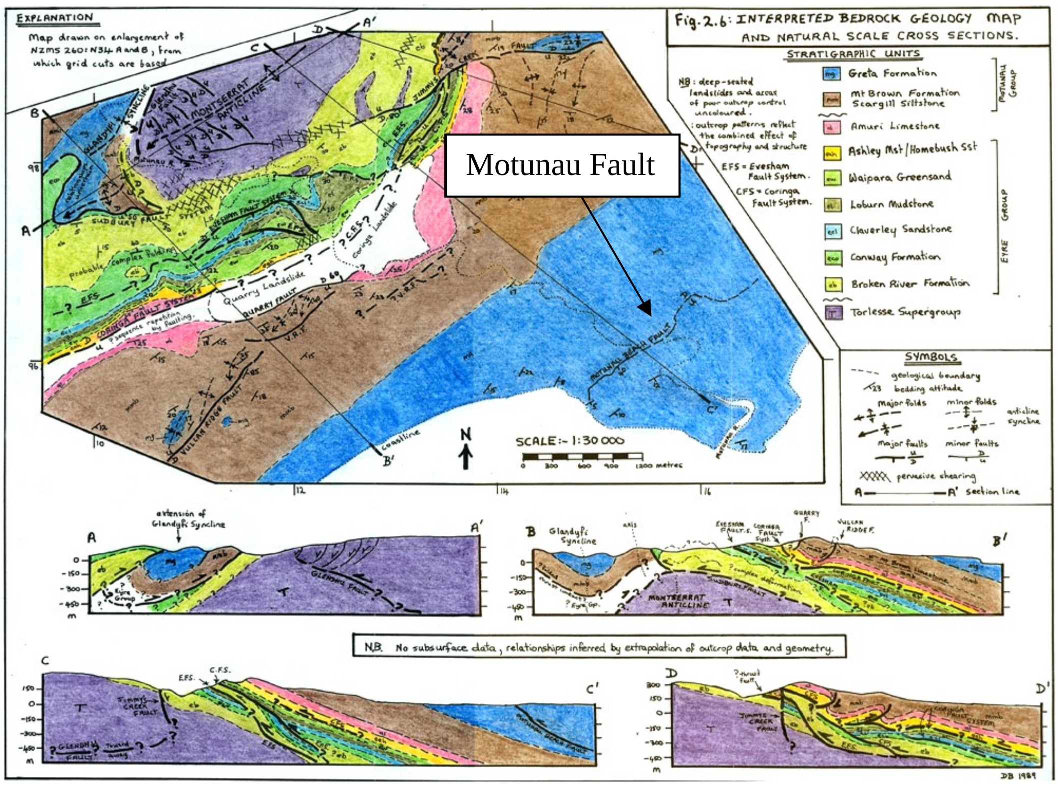


Figure 3.4 Bedrock geology of the Motunau Coastal plain. Note the location of the Motunau fault line through the centre of the blue Greta Formation (Barrell, 1989).

Situated 8 km south off the present Motunau Beach coastline is the submerged and in-filled Motunau Canyon (Figure 3.5). This buried canyon is approximately 65 km in length and 12 km wide. Its south to north orientation indicates the predominant direction of longshore transport processes during the late Pleistocene. With the growth of the Pegasus Canyon, the Motunau Canyon gradually began to fill with fine sediments as the coarser gravels were intercepted from the south. Infilling began before 195,000 to 128,000 yr BP, and was complete prior to the last interglacial around 128,000 yr BP (Herzer and Lewis, 1979). The significance that this historic feature presents is the series of feeder channels that may still exist around the Motunau promontory. During lower sea levels these feeder channels may have linked the Motunau River and the Motunau canyon. These feeder channels may be influential in the offshore flow of sediment via longshore drift from the Motunau River mouth and Sandy Bay. This is supporting evidence for the need of a detailed understanding of the bathymetry and an analysis of the wave environment around the Motunau promontory.

The current Motunau landscape is the result of the combined long-term effects and interactions between bedrock, tectonic uplift, and active geomorphic processes (Barrell, 1989). The reasons for the rapid changes in shoreline morphology across the length of the entire promontory are not clear. This is partly because of the complex of coastal interactions that are taking place.

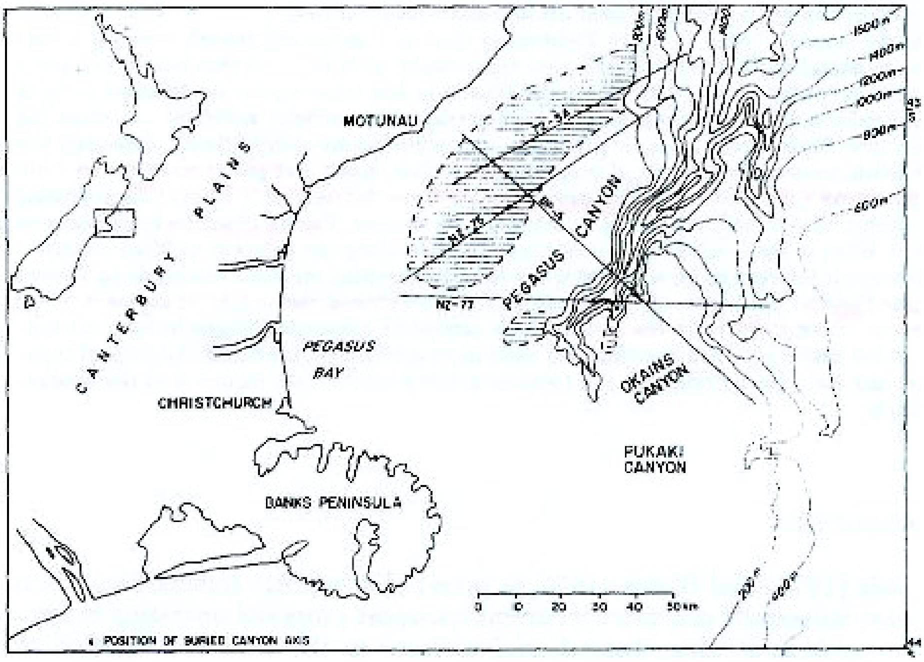


Figure 3.5 An indication of the bathymetry offshore of the Motunau promontory, the existing Pegasus Canyon, seismic profile lines, and the location of the buried Motunau Canyon (Herzer and Lewis, 1979, p.69).

Figure 3.6 shows the dominant sedimentary facies on the continental shelf around Pegasus Bay and Motunau Beach. Shaded areas represent sediments made up of more than 50 % mud. The stippled areas include sediments containing more than 10 % gravel. The unshaded areas represent sand with less than 50 % mud and local traces of gravel. The shelf edge is represented by a broken line (Herzer and Lewis, 1979).

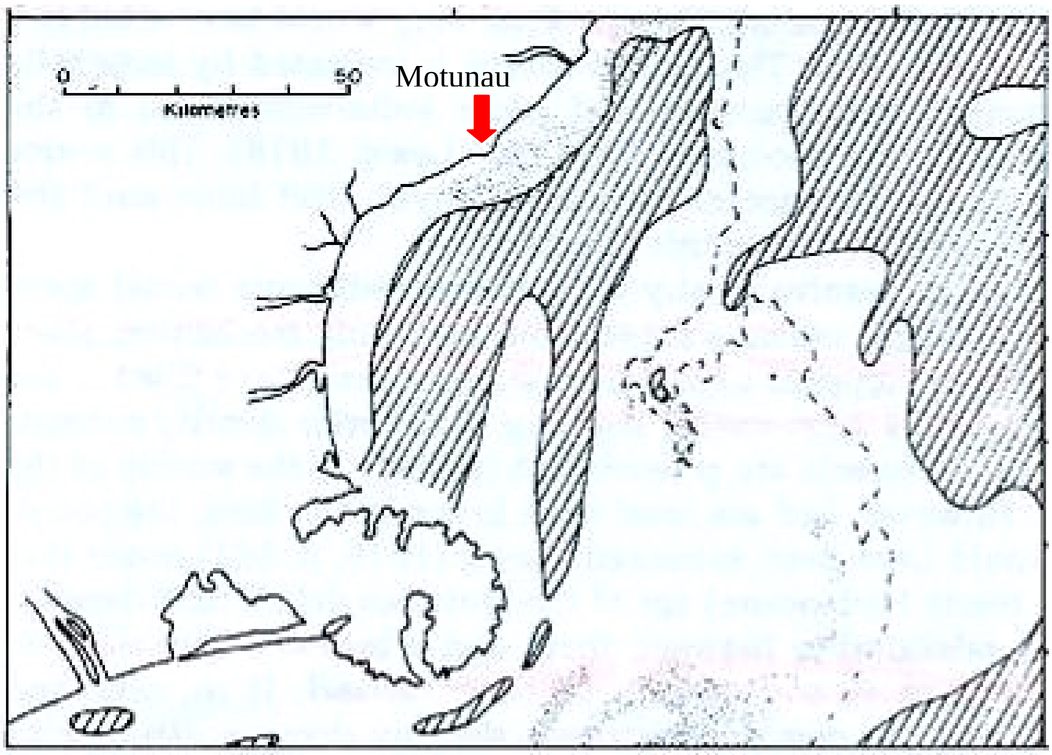


Figure 3.6 Offshore sediment characteristics around Motunau Beach (Herzer and Lewis, 1979).

3.3 The Evolution of Sandy Bay

Sandy Bay is a low gradient sandy beach, its orientation, east to west, suggests that it is exposed to southerly sea conditions (Figure 3.7). The beach is backed by a reflective coarse gravel beach with material in the mean grain size of 78 mm. This consists of a limestone and sandstone composite.

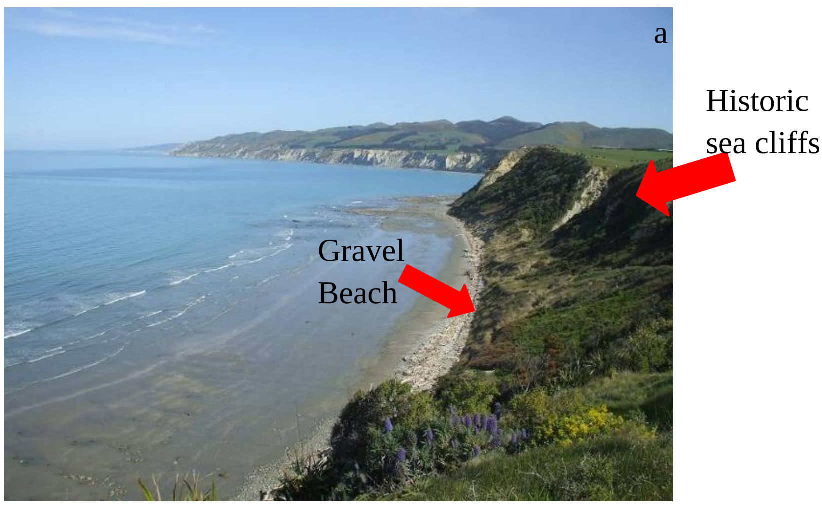


Figure 3.7 a) Sandy Bay photograph looking west (17th August 09). b) View looking east from Sandy Bay. Note the high tide level at the base of the sand dune system in the left of the photograph (April 09). Erosion of the cliffs has reduced the bays ability to accumulate sediments. The hashed line represents the historical extent of the cliff line.

The historic cliffs that back the sand dunes on Sandy Bay are indicative of the last maximum marine transgression, reached 6,500 yr BP (Jennings and Smyth, 1987; Shulmeister and Kirk, 1997; Carter et al., 2002). The dune system that is currently exposed to erosion on Sandy Bay became established over the last 5,000 years as sea level has adjusted and stabilized (Figure 3.7). Prior to the development of sediments in Sandy Bay the coastal cliffs, adjacent to the mouth of the Motunau River, would have been more pronounced than they are today (Figure 3.7b). The cliffs formed a natural obstruction in the path of the sediment transport, predominantly in a northwards direction, resulting in the depositional feature that is Sandy Bay. During these periodic phases of sediment accumulation Sandy Bay could be termed a sediment sink. As Sandy Bay developed and aggraded seaward sediments would have accumulated at the base of the cliff. The formation of this sediment buffer periodically prevented the sea from encroaching to the cliff foot (Jennings and Smyth, 1987). This is one explanation for the period of stability leading up to the increased rate of retreat in the early 1950s (Figure 3.8).

Sandy Bay is confined between two eroding promontory cliffs and rock shore platforms. These are characteristic of a pocket beach (Brunel and Sabatier, 2009). The headlands on either side of the pocket beach provide lateral protection from storm erosion. Over the last 5,000 years a combination of wave attack and subaerial weathering has led to the degradation and erosion of the headland cliffs. From observations it appears the cliff system at the eastern end of Sandy Bay has experienced a greater rate of retreat than the cliffs at the western end. The lateral protection of the sandy beach towards the eastern end has been compromised. Sandy Bay was then exposed to wave attack from variable directions and run-up heights that resulted in the net loss of beach sediments. The beach is backed by an interglacial high stand sea cliff which was the active shoreline prior to build up of the current dune system.

Figure 3.8 View looking southwest along Sandy Bay. Note the extent of the sand dune system prior to the increased rate of erosion in the 1950s (Photograph taken late 1930s).

At its widest point the coarse unconsolidated gravel beach is approximately 14 m wide nearest to the eroding cliffs. It progressively thins further away from the eastern end of the beach to an approximate width of 2 m (Figure 3.9).

Figure 3.9 Size of material on gravel beach along the length of Sandy Bay. Note the mixed sediments in terms of size range and lithologies of greywacke and limestone (Photograph taken 26th July 09).

Atop this gravel layer there is presently a layer of tightly packed driftwood and debris ranging from large tree stumps, to 5 m lengths of timber with thicknesses of around 120 mm. The wood is willow indicating that it has potentially originated from the Motunau River catchment and has been scoured from the catchment during large river flows. The last significant flow was in August 2008. Unfortunately flow recordings were not measured as gauges were destroyed. Looking along Sandy Bay the distinct layers in driftwood, which indicate past high river flow and sea level events, are clearly visible (Figure 3.10). The orientation of the river mouth, which faces a southerly direction, suggests high river flows may expel the debris towards Sandy Bay. Wave action then brings the debris onshore where it is reworked and sorted by tidal processes. The gravel beach deposit and debris layer lies at the base of the eroding dune system. The dune system is characterised by a consistent erosional scarp along the length of the beach. The reflective layer of stone and wood protects the erosional scarp allowing the buildup of slump debris from the dunes. It appears the coarse deposits are acting as a naturally occurring wave-trip wall. Erosion appears to be most evident in the areas of Sandy Bay that are not protected by gravel and drift wood, for example, the western end of the beach.

Figure 3.10 Photograph looking east towards eroding coastal cliffs from Sandy Bay. Note the two distinguishable layers of driftwood indicating previous storm events (Photograph taken 29th June 09).

3.4 Human Influence and Current Morphodynamics

The first European farm in the Motunau Beach area was established in 1847 (Cox et al, 1967). However, there are a series of recorded Maori midden sites, in the area associated with Ngai Tahu. These are sites where food is prepared and cooked. These sites indicate an earlier use of the Motunau promontory. One of the midden sites has been dated at around approximately 460 yr BP (NZ Historic Places Trust, 1969; Canterbury Conservancy, 2007; Mr Ian Hill, Department of Conservation, *pers.comm.*, 2009). In the early 1900s the lower reaches of the Motunau River were used by European farmers as a small natural harbour for the wool trade and fishing industry. Also at one stage a small whaling station was set up. This, however, only lasted approximately two years. Little in the way of physical manipulation of the cliffs, Sandy bay, or the river mouth had occurred during this time as can be seen in Figure 3.11. Refer to Appendix A for a timeline of events.

Figure 3.11 a) Looking south at the Motunau River mouth early 1900s. Note the woolshed to the left used for storing wool (sourced from Ronnie Lee Motunau resident, 2009). b) Photograph taken upstream of the Motunau River mouth looking south towards the river mouth early 1900s. Note the established grassy paddocks and lack of large trees (sourced from Ronnie Lee Motunau resident, 2009).

3.4.1 Early problems

The Motunau Beach shoreline had remained stable up until 1894 or earlier (Barrell, 1989) (Figure3.12).

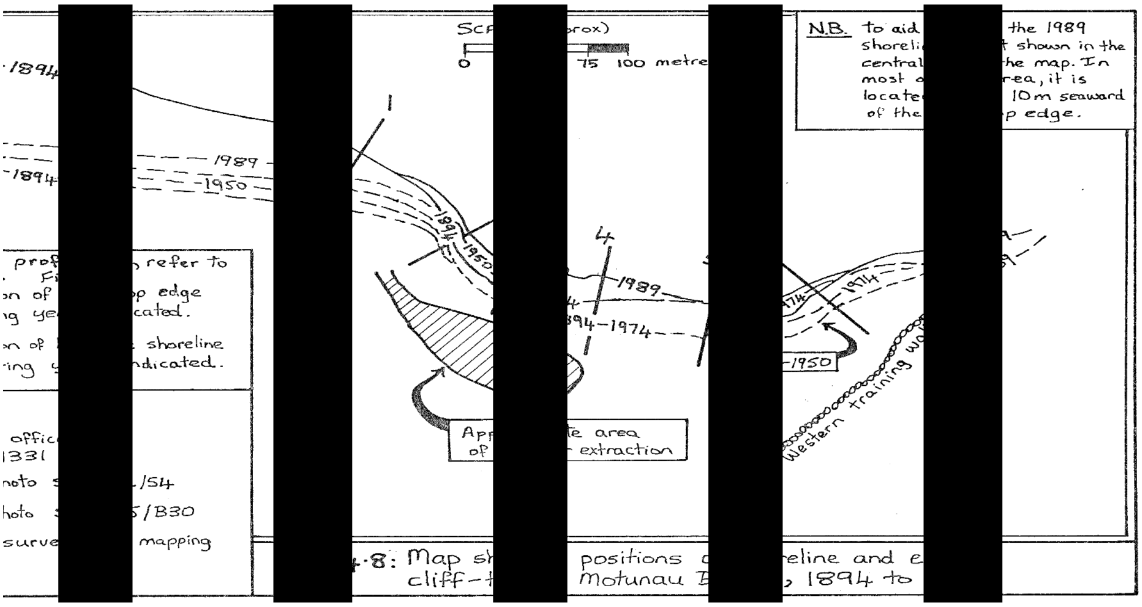


Figure 3.12 The position of the shoreline and cliff line at Motunau Beach between 1984 and 1989 (Barrell, 1989).

The period following 1950 is associated with the progressive erosion of the shoreline and loss of beach width. It is interesting to note that prior to the 1950s there was very little by way of a settlement in Motunau Beach (Figure 3.13). Since then, however, there has been a progressive development of the area, not only with holiday homes but also permanent housing. One explanation for this increased rate of erosion could lie in the fact it only began to be recognized post 1950s. There were more people occupying the area and living there permanently and so physical changes were more readily noticed. Supported by previous examples from Barrell (1989), the current erosion taking place at Motunau Beach is not a contemporary issue. It appears it is part of a larger-scale of long-term coastal change. This coastal change has been related to the retreat and advance of global ocean levels. The current shoreline morphology indicates that the erosion at Motunau Beach has been an ongoing process, as can been seen by the position of Motunau island, over the last 5,000 years. The extent and rate of sea level rise has occurred at temporal and spatial variations which mean that there has been a series of sporadic periods of sediment erosion and sediment accretion around the promontory.

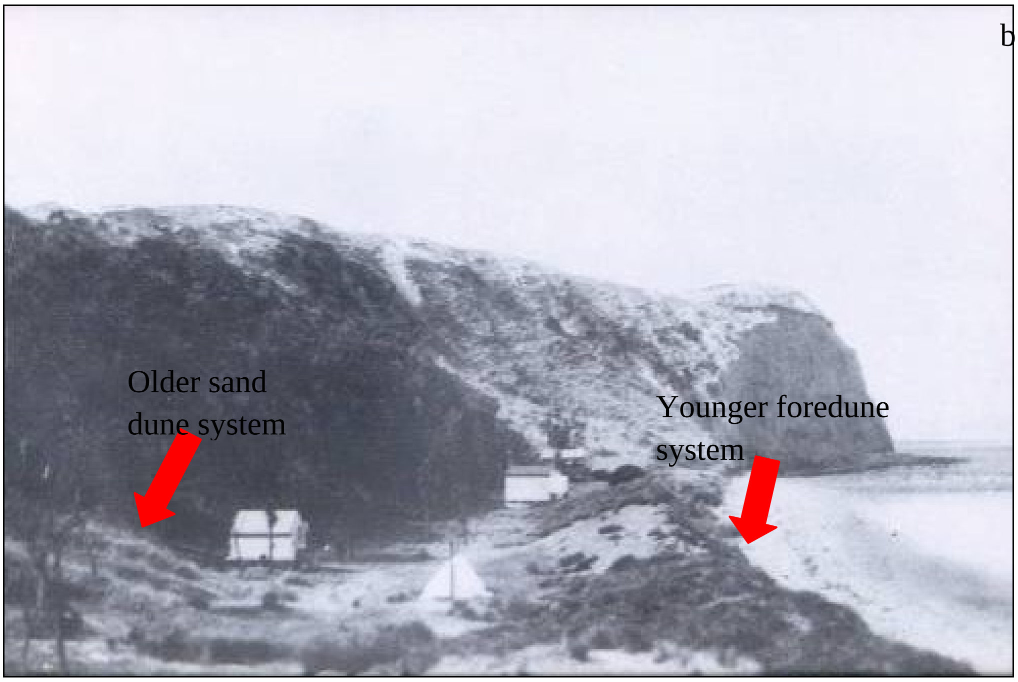


Figure 3.13 a) Vertical aerial photograph taken on the 10th October 1950. This photograph highlights how un-established the Motunau Township is at this time. The residential development atop the eroding coastal cliffs, in the centre of the image has not yet been built. This photo was taken at a 1:18000 scale at approximately 8.38 am and the tide height was -0.93 m. b) Picture taken looking east from Sandy Bay in the early 1950s towards the eroding coastal cliffs prior to erosion problem. Note the position of the high tide level and presence of a foredune (sourced from Simon Foster, local resident, 2009).

3.4.2 Response to erosion issue

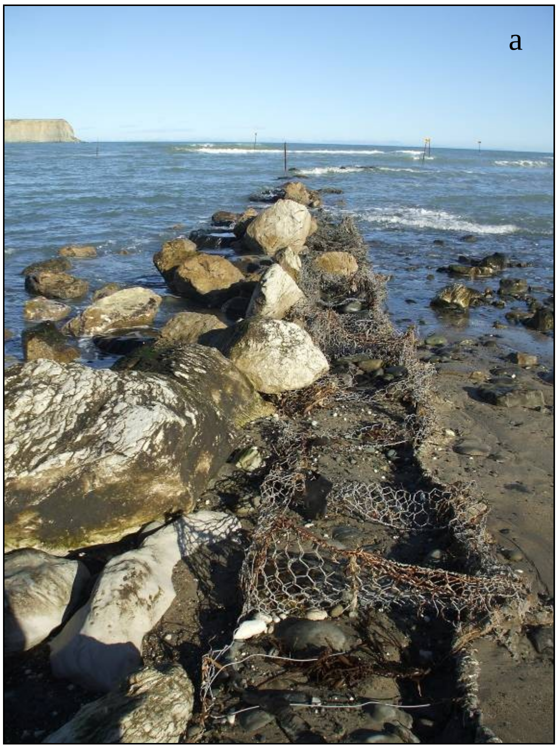
The first official reference to coastal instability in Motunau Beach was in a North Canterbury Catchment Board report dated 1970. The erosion concern at this time was along the western bank of the Motunau River mouth, the site of the current picnic area and carpark (R.W. Morris and Associates, 1987). About this time the holiday homes that were positioned in the dunes on Sandy Bay were also coming under threat from wave action (Mr Bill Foster, owner of Sandy Bay holiday home and local resident, *pers. comm*., 3/7/2009) (Figure 3.13). As a solution to the erosion problem along the river bank a large area of the shore platform at the base of the cliffs, adjacent the river mouth was, stripped of rock to reinforce the river bank and construct a river training wall (R.W. Morris and Associates, 1987).

After the river bank was reinforced between the 1970s and 1980s, there was a marked increase in the rate of cliff collapse to the west of the river mouth. 20 m of cliff retreat had occurred between 1974 and 1985, along with 1 m of basal lowering of the shore platform where the rocks had been removed previously in 1971 (R.W. Morris and Associates, 1987, 1988). It was not until 1983 that this cliff erosion began to threaten houses a top the eroding cliff. In 1985 Dr R.M. Kirk was contacted with regard to the erosion problem. He concluded that Motunau displays a high range of natural coastal erosion and that the removal of the platform rock has accelerated the process. Kirk acknowledged the need for a detailed study of wave refraction patterns and good bathymetric information of Motunau Beach to better understand coastal processes (R.W. Morris and Associates, 1987, 1988). Research and monitoring into the rates and mechanical processes of cliff erosion continued up until 1988. Following which, in 1989 a wire gabion basket wave trip wall was constructed along the toe of the eroding cliff. It was hoped these wire baskets would collect debris falling from the cliff and limit the amount of material removed by wave action, in due course stabilising the cliff face. At this time the inshore 50 m of river training wall was also maintained with the gabion and cloth material (RETECH, 1991a/b). In the period between 1971 and 1989 another river training wall had been added to the seaward side of the river. This wall was constructed out of precast concrete blocks probably by local residents or the local fisheries association. In 1991 another precast concrete block groyne had been built by local residents between the base of the cliff and the gabion basket sea wall.

In 1990 eight transverse shore profiles were established along the length of the coastal cliff section adjacent to the river mouth in order to monitor coastal change (RETECH, 1990, 1991a/b). Since the RETECH (1991a/b) reports little or no reference has been made to the maintenance of the existing structures or the continued erosion management at Motunau Beach. The water depth within the lower reaches of the Motunau River channel during low tide has been an issue affecting channel navigation since the late 1990s. It is well known that high river flows are required to sustain the use of the river channel. During summer months, and months with low rainfall, a series of dredging operations have been carried out in order to remove the sand that has naturally accumulated in the river. Dredging the river of sand acts as a temporary solution to the problem as access is regained for short periods. Conflicting interests between the Department of Conservation (DoC) and local residents has limited the success of the dredging operations.

3.4.2 Current standings

To date the wire gabion baskets have been destroyed by a number of processes including wave attack and human interference (Anderson, 1999). The channel guides are in grave need of maintenance and repair (Figure 3.14). No sufficient maintenance work has been carried out on either of the two channel guides; instead, piecemeal attempts have been made with inadequate materials. For example, tractor tires, to strengthen them (Figure 3.13). R.W. Morris and Associates (1988) outlines some of the environmental consequences and physical changes expected to occur over the next 20 years with regard to the eroding cliffs and threats to property. These threats include; the dynamic river mouth and navigation safety, the erosion of Sandy Bay and the loss of a recreational asset. The current situation in Motunau Beach is that all of these points have eventuated. People have been aware of the threats since the 1980s yet have failed to act upon the hazards in an appropriate manner. The local residents continue to dredge the river when the depth becomes an issue despite the short-term durability of their efforts. The eastern training wall of concrete blocks has subsided into the river channel as was predicted in the R.W. Morris and Associates report (1988). People continue to occupy the houses on the edge of the eroding cliffs. In addition, the land along the top of Sandy Bay has been subdivided and houses are now being built that back onto the hazard boundaries that exist in Motunau Beach (Figure 3.15).



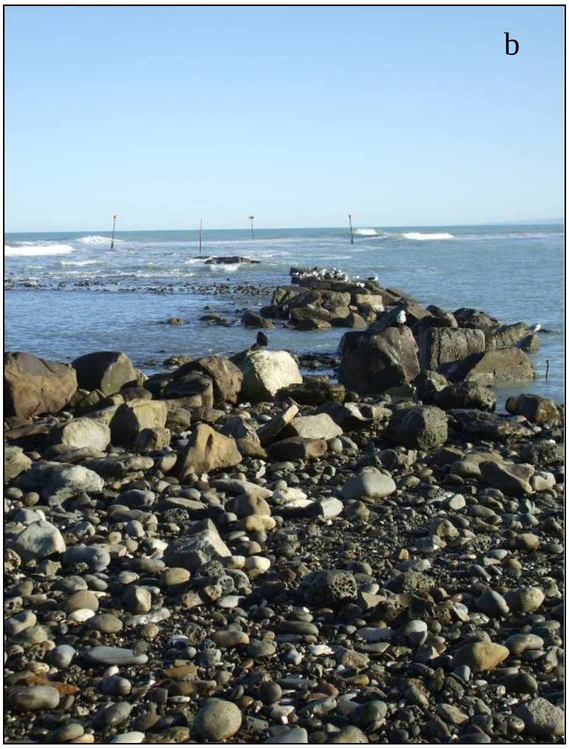


Figure 3.14 Current conditions of the training walls of the Motunau River. Photographs facing south on the 18th June 09. a) Western wall; Note the condition of the Gabion baskets installed in early 1990s. (b) eastern wall; precast concrete blocks installed in the early 1990s by residents have subsided into the river channel offering little or no protection from waves at high tide.

3.5 Groups Involved in the Management of Motunau Beach

The Motunau promontory is managed by the combination of DoC, the Hurunui District Council (HDC), and Environment Canterbury (ECan). All of whom manage specific land parcels for different reasons. ECan currently monitor shoreline changes through profiles. This meets their obligations under section 35 of the Resource Management Act (1991). Due to time and money constraints they have had to prioritise three profiles out of the original eight (Cope et al., 1998; Gabites, 2006). These three profiles are at the eastern end of Sandy Bay beneath the eroding cliffs. ECan have outlined hazard zone boundaries to ensure a buffer exists between the sea and property development (Figure 3.15). These boundaries may need to be re-evaluated taking into account modern rates of shoreline retreat, beach erosion, and shore platform lowering that are specific to the Motunau promontory.

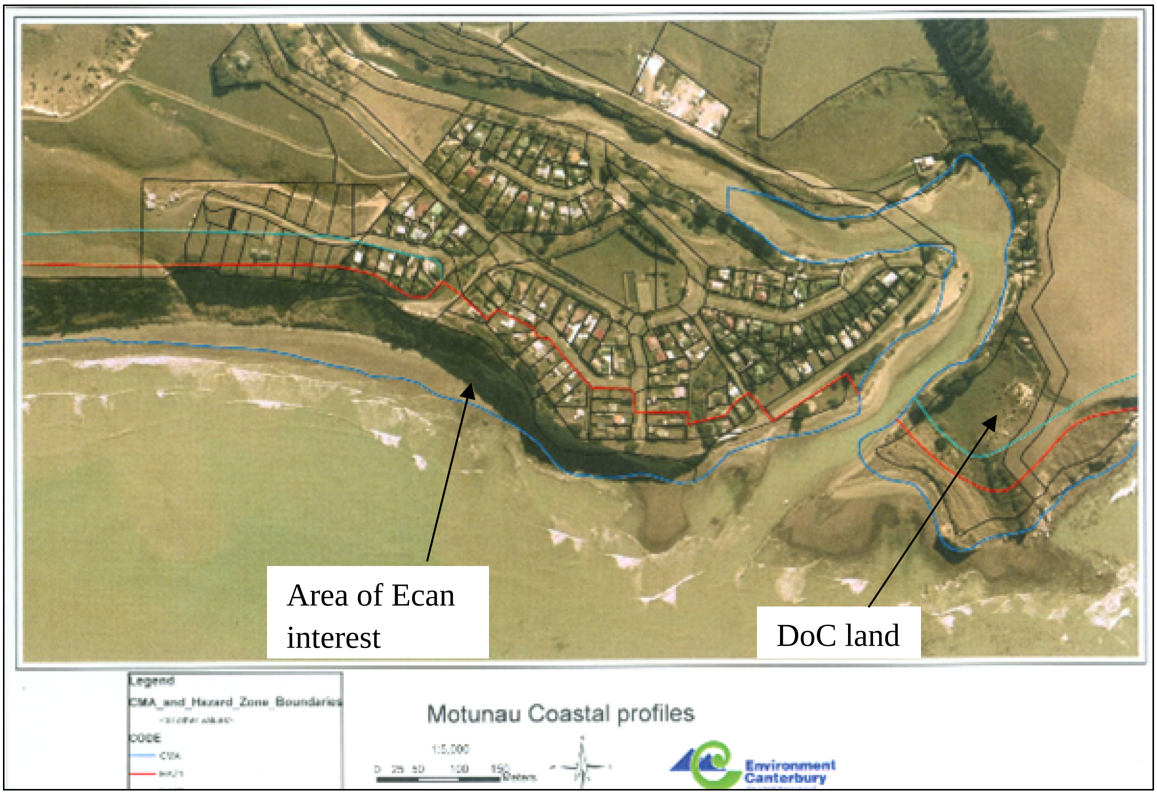


Figure 3.15 Outline of hazard zone boundaries and property boundaries at Motunau Beach. Available from ECan 2009. Red line indicates boundary of the highest risk zone.

The DoC has interests in the 4.0851 ha small tract of land on the true left of the Motunau River under section 62 of the Conservation Act (Figure 3.15). This is due to the presence of the native grass Pingao or *sp Desmoschoenus spiralis*. This section of land also contains a nesting site for a colony of Pied Shag or *sp Phalocrocorax varius*. Their management strategies include weed control and retaining the habitat for the Pied Shags (Ian Hill and Bruce Arnold, *pers. comm.*, DoC, 2009). Access across this land to dump river dredging has been denied due to the detrimental effects posed by heavy machinery. The third party involved in the management of Motunau Beach is the HDC. According to the Hurunui Community Plan (2009) the council has a statutory requirement under the Reserves Act 1977 to provide and maintain parks, reserves and recreation areas for the benefit and enjoyment of the public. Their key responsibilities are ensuring accessibility, and the preservation of native vegetation, ecosystems and heritage (Hurunui Community Plan, 2009).

3.6 Chapter Summary

From the review of available information on the history of Motunau Beach it appears the contemporary rates of erosion can be attributed to a larger-scale process of sea level rise with fluctuating rates of advance. Human settlement has increased over the last century and has resulted in conflicting use of the area. The resulting lack of management in response to physical change and morphodynamics at Motunau Beach is due to inconsistent use of the resource by the DoC, ECan, the HDC, as well as local residents. Furthermore, it appears there is a clear miscommunication between the management groups involved leading to the misuse of the Motunau area. Detailed information on the physical processes of shoreline change needs to be more accessible to the public and users of the Motunau promontory in order for a more accurate management response to be implemented.

Chapter Four

Local Climate of Motunau Beach

4.1 Introduction

Chapter Four provides a description of the atmospheric climate along with the ocean wave environment of the Motunau area. It addresses the following questions; what are the processes causing cliff erosion at Motunau? How is the bathymetry of the nearshore zone linked to changes in shoreline morphology? Section 4.2 discusses the rainfall patterns at Motunau Beach, which tie into the Motunau River flow characteristics outlined in Section 4.3. Section 4.4 describes the general wave climate for the east coast of the South Island. In Section 4.5 the 20 year hindcast (1979 to 1999) wave data has been analysed to examine trends that are specific to Motunau Beach. Section 4.6 then looks at the more recent 10 year nowcast wave data that covers the period 1997 to 2008. Section 4.7 outlines the results of wave climate analysis from the three month field study period July to September 2009. The analysis of the Motunau Beach wave climate will provide a background understanding of wave conditions at Motunau and links to changes in shoreline morphology. Furthermore, indicating potential implications for future shoreline morphologies at Motunau.

4.2 Motunau Beach Rainfall

Motunau Beach received on average 727.11 mm yr^{-1} of rainfall between the years 1992 and 2009. Following a seasonal trend, the rainfall increases around the month of May and then begins to decrease again around September. This trend is also comparable with the seasonal temperature trend (Figure 4.1). Large floods that are the result of high rainfall events, and that are of sufficient magnitude to scour the Motunau River mouth, appear to occur when monthly rainfall totals are in excess of 200 mm. Three significant downpours of this magnitude have occurred since 1992; In June 1995, 329.4 mm; January 2002, 299.4 mm; and in August 2008, 224 mm (NIWA, 2009). Monthly averages of approximately 84 mm were recorded in 2008. During this year the highest monthly rainfall occurred in February, May, July and August. Unfortunately, river flow velocities were not recorded during these times due to loss of recording equipment. High river flows at Motunau Beach are not a priority for any environmental monitoring strategy (Miss Kerrie Osten, ECan Hydrological Analyst, *pers. comm.*, 23/7/2009).

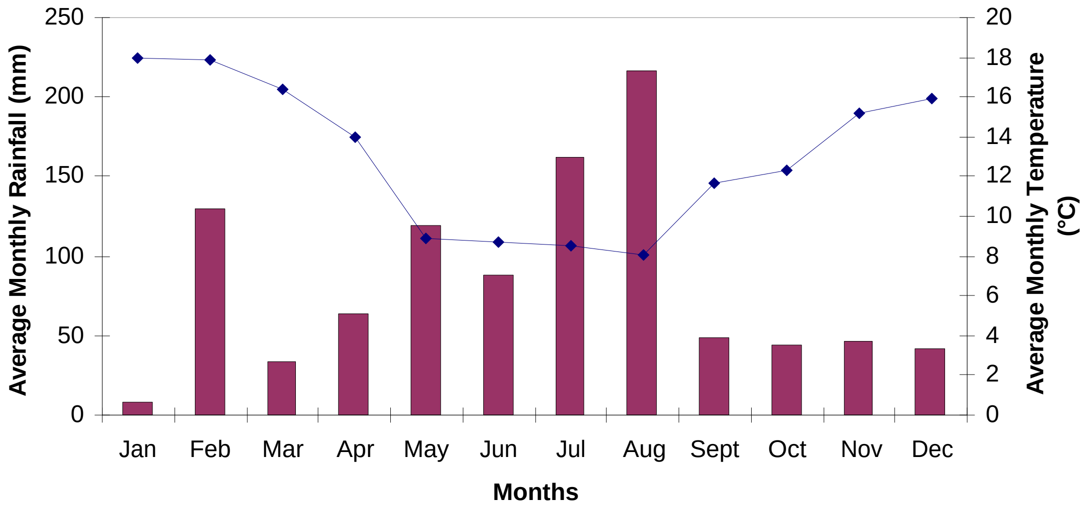


Figure 4.1 Average monthly temperature and rainfall for Motunau in 2008. Data sourced from NIWA (2009) and Wunderground Weather (2009)

4.3 Motunau River flow

The Motunau River catchment does not drain from the Southern Alps across the Canterbury foothills or Canterbury plains. Instead it originates in the hills surrounding Mt Vulcan and is characterised by a steep relief (Figure 4.2). The most common catchment land use is sheep and cattle farming. There have been no large-scale river diversions in the Motunau River catchment in order to irrigate the surrounding land. One of the implications that farming has had on the area is that the land has been historically cleared for grazing. Despite having small vegetated gullies the majority of the Motunau catchment consists of grass and tussock hill slopes (Figure 4.3). With this relatively bare land there is an associated water runoff that is faster when compared to forested catchments.

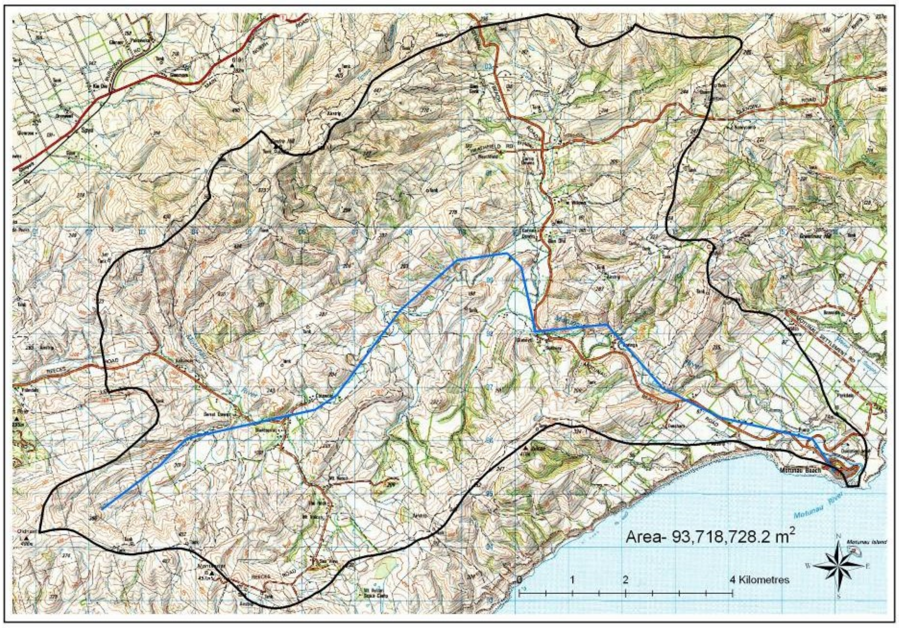


Figure 4.2 An outline of the Motunau River catchment (available from Ecan, 2009).

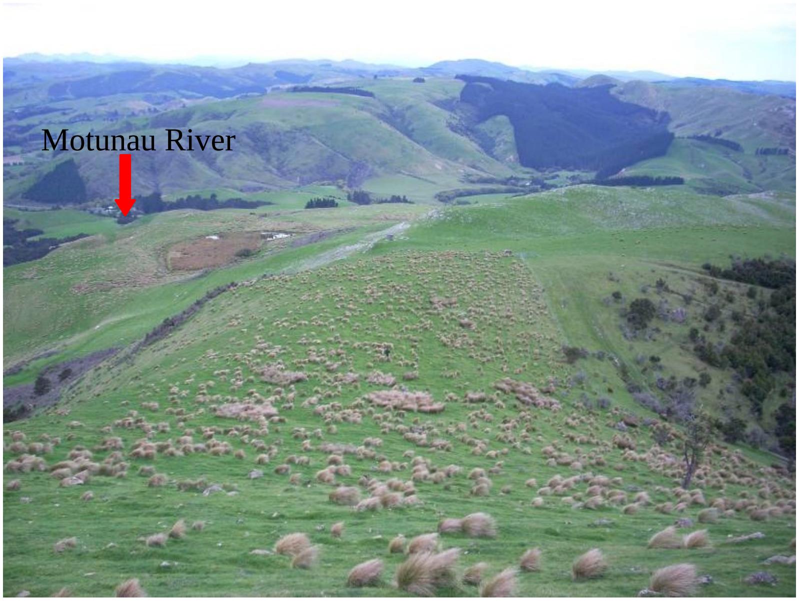


Figure 4.3 Example of land cover in the Motunau River catchment. Photograph looking northeast. 4th April 09.

These catchment characteristics have implications for the river flow of the Motunau River. The Motunau River has had a series of short-duration and high-magnitude floods, the most recent of which occurred in August 2008 (Figure 4.4). From the observations of river flow and rainfall data during the months July to September 2008, it is known that the Motunau River can, and has in the past, excessively flood to an extent that can wash out roads, remove large willow trees from the river banks, and drastically scour the Motunau River mouth of coarse sand. This process has repercussions for the local fisheries in terms of access to and from the lower reaches of the Motunau River mouth.

A minimum flow standard has existed for the Motunau River since 1983. This was initially established under the Water and Soil Conservation Act (1967) and then continued under the Resource Management Act (1991). In 2004 the minimum flow level was revised by ECan and is continually monitored during the summer and autumn months (December to May). The river flow data that is available from ECan has been recorded using both fixed flow and a flow tracker gauges. The data retrieved from these recordings is incomplete due to floods in 2008 and problems with equipment (Miss Kerrie Osten, ECan Hydrological Analyst, *pers. comm*., 23/7/2009). The river flow data is biased towards summer low flows for the purpose of management of water extraction from the river. From the data that is available, the flow during the summer months is calculated to be around 0.328 m s^{-1} with a velocity of approximately 0.239 m s^{-1} (ECan, 2009b). However, these results are based on very piecemeal river flow data.

Due to these regular low velocity river flows it would appear that very little sediment deposition occurs as a result of river flow alone. Instead, deposition of sediment around the lower reaches of the Motunau River tends to be the result of the flood phase of the tide cycle. The incoming tide transfers sediment upstream and then at slack high tide the sediment is deposited. River flows are then insufficient to regularly remove the deposited material.

Figure 4.4 a) Pre flood 6th June 2008. b) Post flood 5th August 2008. Photographs taken approximately 200 m upstream of the Motunau River mouth.

Figure 4.4 shows that after a large river flood the sand material deposited in the lower reaches of the river channel during high tide has been scoured. This has lowered the base level of the river channel exposing the coarser gravels beneath. This also has negative effects for navigation safety within the channel. Figure 4.5 shows the gravel bar that is exposed after large storm events.

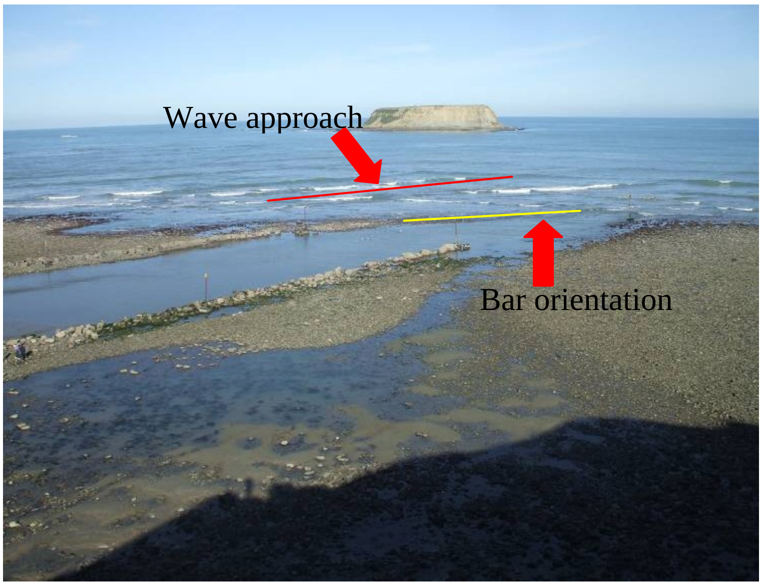


Figure 4.5 View looking south towards Motunau Island and the access point upstream to the jetty and loading ramp. Note the orientation of the exposed gravel bar at the mouth of the Motunau River and the angle of wave approach, July 2009.

According to the Proposed Canterbury Natural Resources Regional Plan (2006), the purposes of the management and a setting of an environmental minimum flow and allocation regime for the Motunau River include:

(1) to safeguard the mauri of Motunau River,

(2) to protect wahi tapu and other wahi taonga of value to Ngai Tahu,

(3) to maintain the natural character and amenity of Motunau River,

(4) to safeguard the life supporting capacity of trout,

(5) to safeguard the life supporting capacity of indigenous species; and,

(6) to provide for the taking of water for out-of-stream use providing sufficient water is retained in-stream to satisfy purposes.

It is interesting to note these flow standards have not been set in order to help sustain the navigational use of the lower reaches of the river for fisheries use. The congestion of the lower reaches by sediment is an obvious consequence of inadequate river flows (Figure 4.6).

Figure 4.6 a) A local fishing vessel heading upstream of the Motunau River mouth towards the loading ramps during high tide (photograph taken 2008). During times of low river flow water levels in the river cannot support the passage of fishing vessels. b) During these times boats must be launched and then recollected at the river mouth. As a result, this poses an obvious danger to vessels (Photograph taken 2008).

4.4 Motunau Beach Wave Climate Analysis

Southwesterly (SW) to easterly (E) waves dominate the South Island's east coast. These waves are derived from the large southerly (S) waves associated with New Zealand's geographical position on the 40° latitude belt, also known as the roaring 40s (Shulmeister and Kirk, 1997; Crundwell et al., 2008). In the Southern Ocean the mean wave energy direction is eastwards due to the prevailing westerly wind system (Gorman et al., 2003b; Crundwell et al., 2008). As shown in Figure 4.7. Large southerly waves progress up the east coast of the South Island and are then refracted around Banks Peninsula and into Pegasus Bay. In general, these large waves continue up the coast towards the northeast with diminishing height. This means there is little wave energy propagating in a southerly direction. The decrease in wave height to the northeast is due to the blocking effects of the New Zealand landmass (Carter et al., 2002; Gorman et al., 2003b). Despite the east coast's exposure to the Pacific Ocean, the most influential wave climate comes from the southwest of New Zealand (Gorman et al., 2003b).

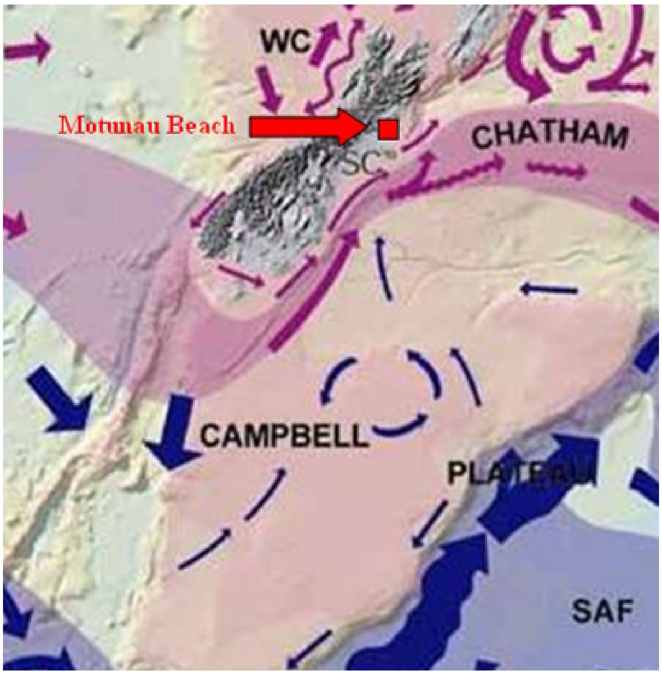


Figure 4.7 The position of Motunau Beach within the broader ocean circulation context of New Zealand. The South Island's east coast is predominantly influenced by SW sea conditions (Available from www.teara.govt.nz, 2009).

During summer months northeast swell is common and hot dry northwest winds occur (Cox et al., 1967). Ocean swell coming from the northeast can be associated with a sub-tropical low located to the northeast of New Zealand. Strong cold southerly or southwest winds are common in winter and are less frequent in other seasons. Most of the rain, that also affects the rest of New Zealand, comes from the southwest. Heavy rain can also come from the northeast (Cox et al., 1967).

The recent analysis of the wave environment at Motunau Beach would suggest that the area is generally characterized by low energy waves. Wave heights average around 1.5 m (Figure 4.8). These heights are also in agreement with Gorman (2003b). The average wave height is further reduced in the nearshore zone at Motunau due to the processes of wave refraction and defraction that are occurring in the shallower lee of Motunau Island. These processes were visible during the three month observations outlined in Appendix B.

a **b**

Figure 4.8 a) Looking southwest along Sandy Bay (August 2009). Note the refraction of low energy waves into the bay, and the pronounced rock platforms at either end of the bay. b) Motunau Island 1 km south is influential in dissipating and redistributing wave energy in the nearshore zone (July 2009).

The position of Motunau Beach within the broader New Zealand wave climate means that the general wave approach direction and prevailing conditions, driving coastal shoreline change, are generally similar to those occurring along the east coast of the South Island. On a smaller site-specific level Motunau Beach exhibits a multipart arrangement of coastal processes. These processes have interacted with the bathymetric contours associated with Motunau Island and the contours connected with the promontory to shape a distinct shoreline orientation (Figure 4.9). These physical controls affect the way deep water waves propagate from offshore water towards the shoreline. This process affects the distribution of wave energy at the shoreline.

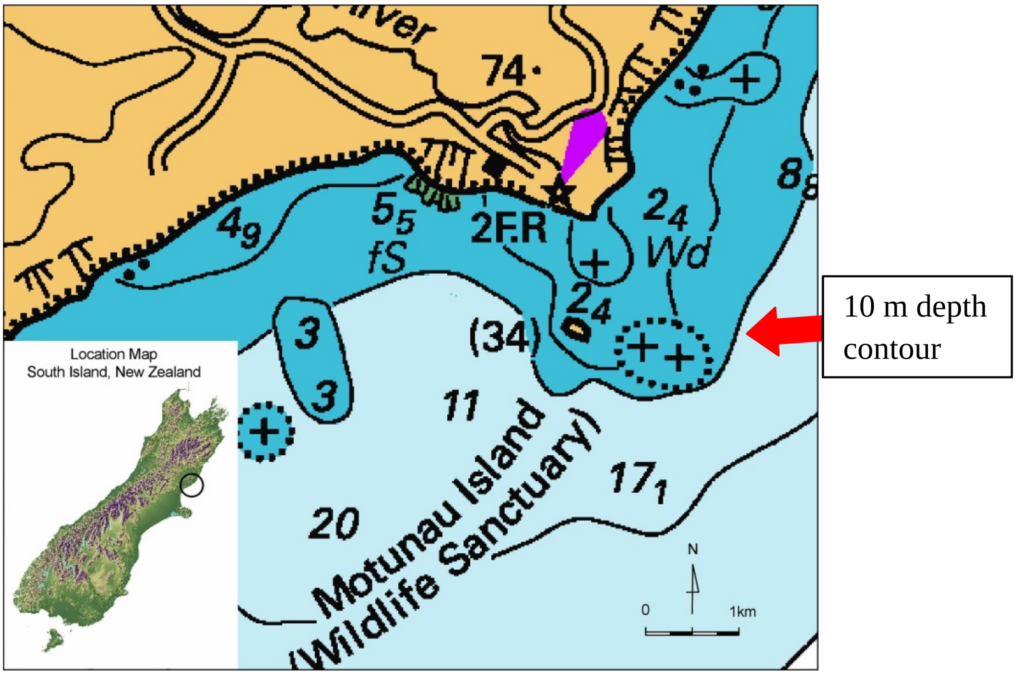


Figure 4.9 Hydrographic chart of the Motunau Beach coastline, depths are in meters. Modified from the 1:200,000 scale chart, available from www.LINZ.co.nz, 2009.

The following wave climate analysis has been modelled using the wave generation model WAM (WAve Model). It is used to hindcast the generation and propagation of deep water ocean waves or those waves not affected by the nearshore bathymetry (Gorman et al., 2003a). The wind data is modelled at the 50 m depth contours, at site location of -43.075, 173.083, and has had a refraction correction up to the 10 m depth contour. This means that following wave statistics are relevant up to the 10 m depth contour. The nearshore wave environment, landward of the 10 m depth contour, is complicated by the presence of Motunau Island and the processes of wave refraction over the bathymetric contours associated with the promontory. Waves are modified by a nearshore zone of varying depths and by the degree of sheltering by the land. This spatial variation means that to accurately monitor a wave environment a combination of both quantitative and qualitative methods is required (Gorman et al., 2003). The WAM wave data can be termed synthetic data as it is not based on existing wave recordings. It is modelled off wind data. The benefits of this modelled wave data is that it provides complete data sets without gaps. It provides valuable information on which we can build understandings and when combined with regular observations is appropriate for looking at general trends and other regularly occurring wave characteristics. Examples include the directions of wave approach, wave heights, and wave periods. For a breakdown of wave observations from July to September 2009 refer to Appendix B.

4.5 NIWA Hindcast Wave Results 1979 to 1999

The prevailing wave directions that have influenced the Motunau promontory over the 20 years 1979 to 1999 have approached the shoreline from a northeast (NE) to south (S) range. The lack of the north (N) and north-northeast (NNE) component is due to the sheltering effect the North Canterbury coastline has on the Motunau area (Figure 4.10). Figure 4.10 indicates that wave heights were relatively consistent across the range of wave approach directions between 1979 and 1999.

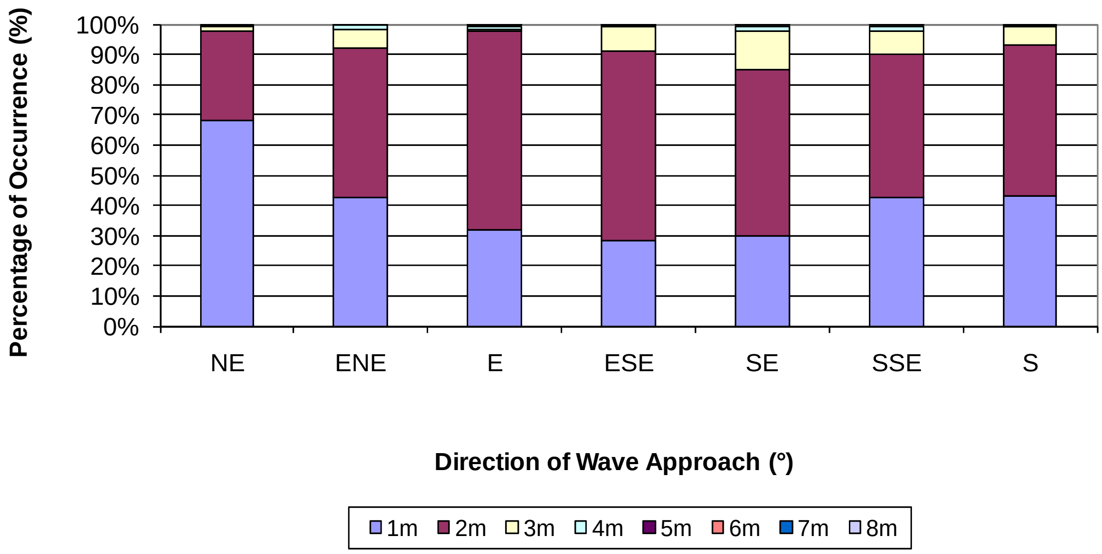


Figure 4.10 Wave approach directions and height frequency at Motunau Beach 1979-1999

For each of the prevailing wave directions the average wave height was between 2 and 2.9 m which occurred approximately 50.94% of the time at Motunau Beach.

Waves that approach Motunau Beach from a southerly (S) direction are the most frequently occurring. This means that their contribution to the overall Motunau wave climate is the greatest (Table 4.1). This analysis agrees with the Gorman et al., (2003) general wave climate description of the east coast of the South Island. It is during the larger southerly and southeast sea conditions that we would expect the most erosion to occur.

Table 4.1 Wave approach directions versus wave height for Motunau Beach and the contribution to the overall wave climate 1979 to 1999.

Significant Wave Height (m)	33.75-56.25 (NE)	56.26-78.75 (ENE)	78.76-101.25 (E)	101.26-123.75 (ESE)	123.76-146.25 (SE)	146.26-168.75 (SSE)	168.76-191.25 (S)
1	2.63	7.06	3.04	1.53	1.14	2.90	23.04
2	1.16	8.25	6.25	3.38	2.11	3.26	26.51
3	0.07	1.08	0.11	0.44	0.50	0.53	3.25
4	0.01	0.23	0.09	0.03	0.07	0.12	0.31
5	0.00	0.02	0.02	0.01	0.01	0.02	0.03
6	0.00	0.00	0.01	0.00	0.00	0.00	0.00
7	0.00	0.00	0.01	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total for all heights (%):	3.87	16.64	9.53	5.39	3.83	6.83	53.14

Wave periods at the 50 m depth contour most commonly have a period between 10 and 12 s (Figure 4.11). This trend was also observable within the nearshore zone at Motunau Beach over the July to September study period (Appendix B).

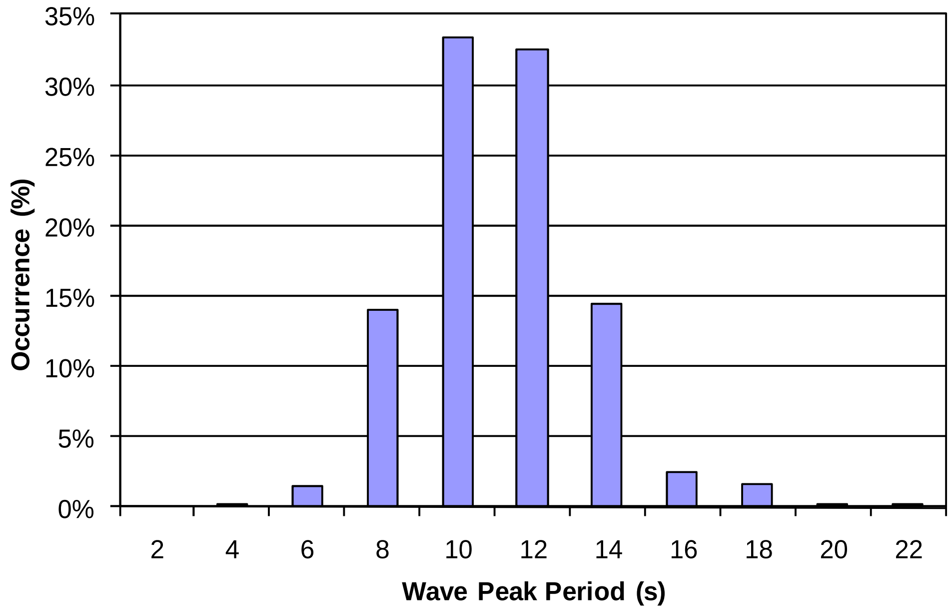


Figure 4.11 Frequency of hindcast wave periods 1979 to 1999 shows the dominance of wave periods in the range of 10 to 12 seconds.

Figure 4.12 shows a clear peak in large wave heights associated with approach directions of between 260° and 280° from north (0°). This corresponds with easterly waves (E). There is also a second peak between 320° and 340° which corresponds to a south-southeast (SSE) wave direction. It appears the general Motunau Beach wave climate beyond the 10 m depth contour is similar to surrounding coastal environments. It is the nearshore zone that determines how these larger waves are going to respond to, and affect, the shoreline morphology. This is because the waves will undergo the greatest modification in these shallower waters.

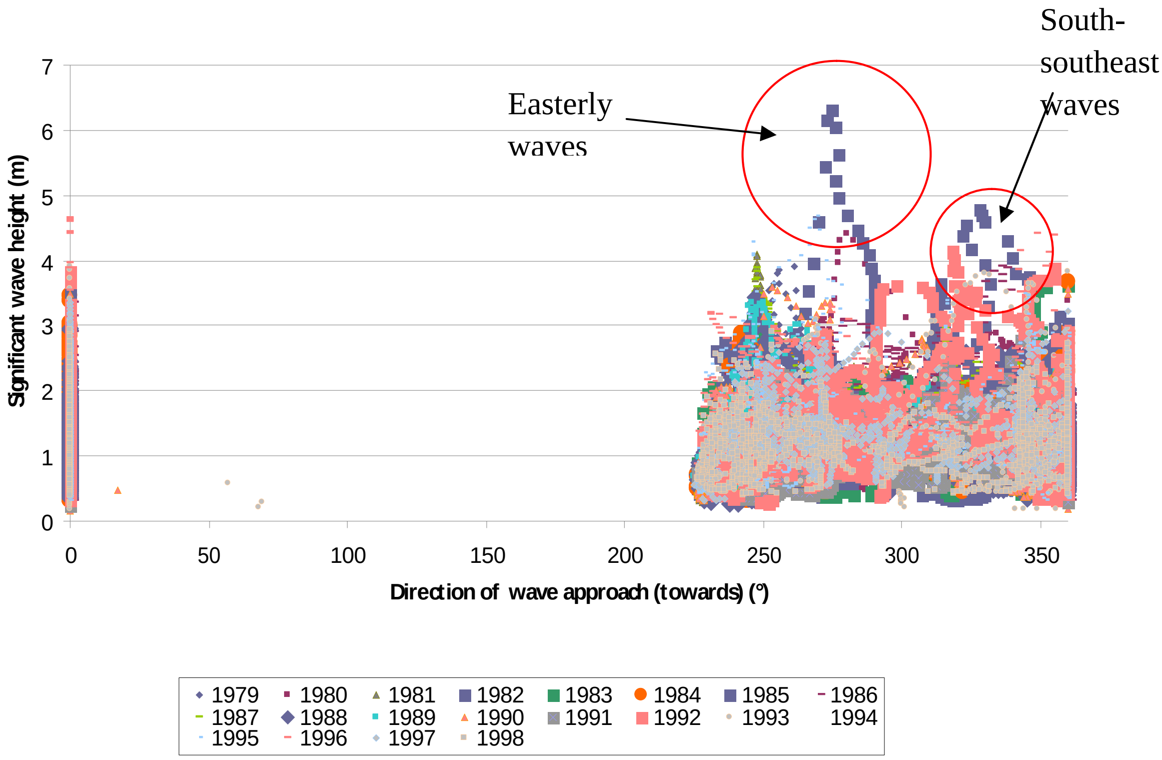


Figure 4.12 Hindcast wave heights and their directions. This figure shows that wave height is relatively consistent from all directions. The large southerly swells approach towards the direction 270 to 360 degrees with heights ranging from 0.5 m to 6.5 m. Direction of approach is in degrees from north (0).

Further analysis of the 20 year hindcast wave data suggests the average wave height was approximately 1.2 m at the 50 m depth contour. The largest waves approached from the east direction. The maximum wave height of 6.305 m occurred on the 27th July 1985. There were also large wave heights from the east-southeast (ESE) with heights of around 5 m. Shoreline profiles for these times were not available. It is during these low-frequency and high-magnitude wave events that we would expect to see the most dramatic erosional changes in the Sandy Bay beach level and loss of cliff. The average wave height at the 50 m contour of 1.2 m is relatively small and by the time these waves have refracted into the nearshore zone at Motunau Beach we would expect them to have dissipated to an even smaller size, from observations around 0.5 to 1.2 m. Lumsden and Kirk (1991) calculated the height of wave needed to reach the base of the cliff at Motunau would have to be approximately 1.2 m in height.

The effects on the shoreline morphology as a result of these small waves is likely to be minimal. The hindcast wave data, in conjunction with historical accounts, supports the suggestion that it is the sporadic higher-energy and low-frequency wave events are responsible for the large erosional events at the shoreline. These high energy events are the drivers that threaten the stability of the Motunau shoreline morphology.

4.6 NOAA Wave Results 1997 to 2008

The analysis of the hindcast/nowcast wave data suggests that between the years 1997 to 2008 the dominant wave direction was in the range from the northeast to the south (Figure 4.13). This is similar to the 20 year hindcast data in section 4.5 and is a reflection on the position of Motunau Beach within Pegasus Bay and the orientation of the Motunau Beach coastline. Figure 4.13 indicates that between the years 1997 and 2008 the wave climate was relatively consistent. This means that wave heights were uniform from each direction of approach.

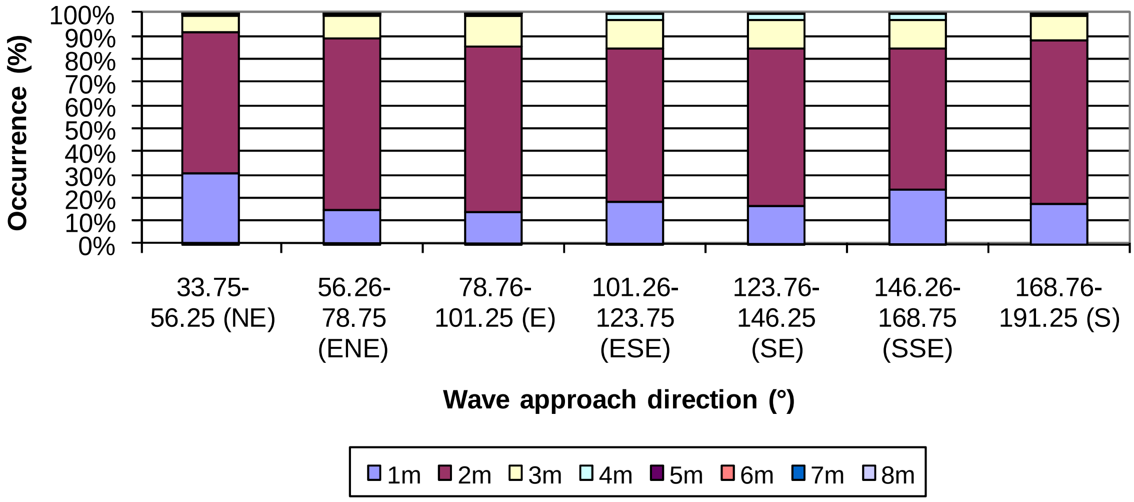


Figure 4.13 NOAA significant wave heights at Motunau Beach 1997 to 2008. Shows the wave heights are similar from each angle of wave approach with the most frequently occurring wave height in the range of 2 to 2.9 m.

The general wave height seaward of the 10 m depth contour was in the range of 2 to 2.9 m. These heights are similar in all the wave directions from the northeast to the south, as was indicated in Figure 4.13. Table 4.2 shows the contribution each wave direction makes to the Motunau wave environment. Southerly wave contributions clearly prevail at approximately 37.35 % of the total Motunau wave climate. This finding fits the previous wave climate analyses of Shulmeister and Kirk (1997), Crundwell et al., (2008), and Gorman et al., (2003 a/b).

Table 4.2 Wave height contribution to the overall wave climate at Motunau Beach 1997 to 2008.

Significant wave height (m)	**33.75-56.25 (NE)**	**56.26-78.75 (ENE)**	**78.76-101.25 (E)**	**101.26-123.75 (ESE)**	**123.76-146.25 (SE)**	**146.26-168.75 (SSE)**	**168.76-191.25 (S)**
1	8.91	1.30	1.61	0.92	0.72	0.87	6.63
2	17.57	6.53	8.13	3.46	2.97	2.30	26.48
3	2.07	0.93	1.48	0.63	0.51	0.43	4.27
4	0.22	0.07	0.14	0.14	0.13	0.11	0.35
5	0.00	0.00	0.01	0.02	0.02	0.02	0.02
6	0.01	0.00	0.01	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total for all heights (%)	28.78	8.84	11.37	5.17	4.35	3.73	37.35

Wave periods are in the range between 8 and 14 seconds. The most frequently occurring wave intervals are 12 seconds (Figure 4.14). This finding also fits the wave intervals observed in the nearshore zone over the three month study period in 2009 (Appendix B).

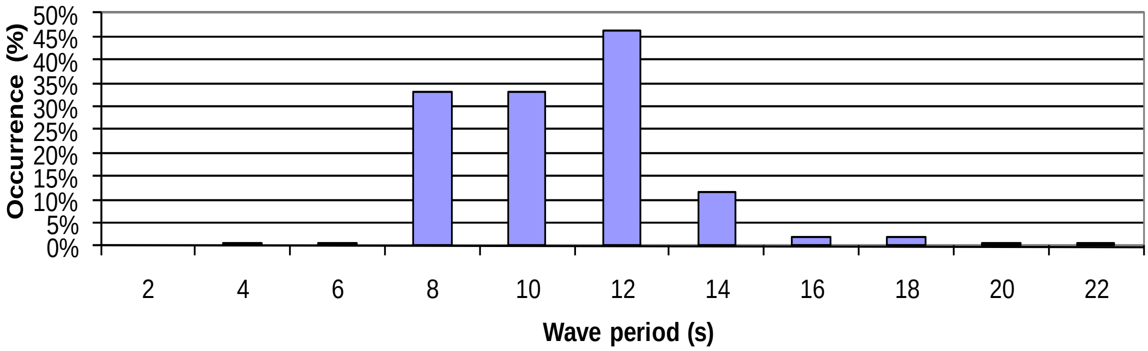


Figure 4.14 NOAA wave periods for Motunau Beach 1997 to 2008.

Figure 4.15 clearly shows that across the range of wave approach directions the wave heights at the 50 m contour have been relatively consistent over the years 1997 to 2008. The wave environment has been punctuated by large-scale and low-frequency wave events that alter this trend. Between the years 1997 to 2008 the wave heights appeared to be consistent within the spectrum of approximately 0.5 m to 4 m, until a large event occurred in 2008 from a northeasterly direction consisting of heights between approximately 4 and 6 m.

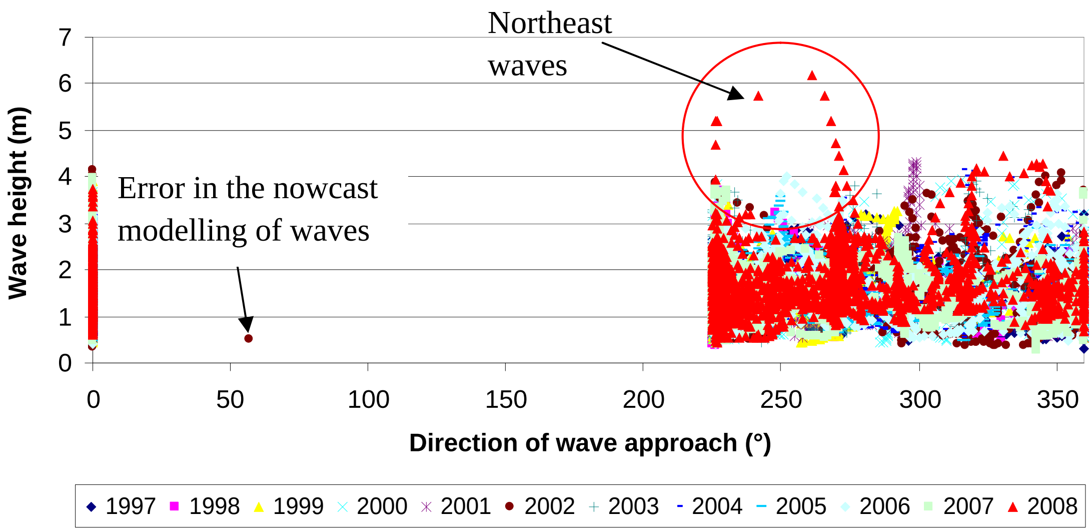


Figure 4.15 NOAA significant wave heights and directions for Motunau Beach 1997 to 2008. X-axis represents angle of wave approach from north (0).

4.7 Motunau Wave Climate 2009

Over the study period 15th June to the 30th September 2009 the offshore wave environment of Motunau Beach was analysed in order to examine the effects of wave height on shoreline morphology. Figure 4.16 shows clearly that the two most influential wave fields are from a northerly direction and a southerly direction. These two distinct wave approach directions are due to the orientation of the Motunau coastline. The lack of northerly and southwest wave approach directions is due to the orientation and sheltering effects of the North Canterbury coastline. This was also indicated in sections 4.5 and 4.6. Figure 4.16 highlights that although the southerly wave sector prevailed it was the easterly sector that appeared to be associated with the larger waves.

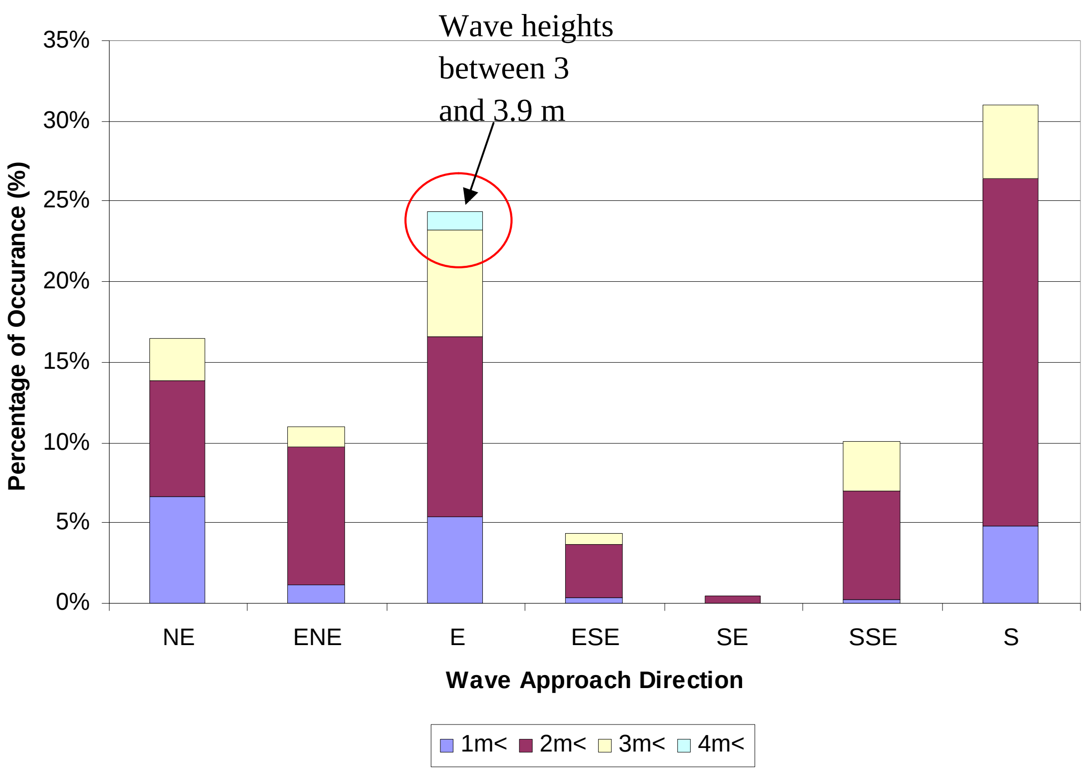


Figure 4.16 Spectrum of wave heights at Motunau Beach from the 15th June to the 30th September 2009.

Table 4.3 represents the wave heights from each prevailing wave direction over the study period and its contribution to the overall wave climate at Motunau. As previously suggested southerly sea conditions are the most frequently occurring due to New Zealand’s position in the roaring 40’s. This strong southerly component was also prevalent throughout this study period. It appeared that there was also an influential easterly element in the 1 to 2 m wave height range. The average wave height for the 2009 period was approximately 1.57 m.

Table 4.3 Significant wave height contribution to the Motunau coast from prevailing wave directions.

Significant wave height (m)	**33.75-56.25 (NE)**	**56.26-78.75 (ENE)**	**78.76-101.25 (E)**	**101.26-123.75 (ESE)**	**123.76-146.25 (SE)**	**146.26-168.75 (SSE)**	**168.76-191.25 (S)**
1<	6.64	1.15	5.38	0.38	0.00	0.24	4.78
2<	7.25	8.54	11.22	3.33	0.45	6.69	21.64
3<	2.54	1.27	6.64	0.64	0.00	3.16	4.54
4<	0.00	0.00	1.15	0.00	0.00	0.00	0.00
5<	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6<	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7<	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8<	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total for all heights (%)	16.42	10.96	24.39	4.36	0.45	10.09	30.96

Figure 4.17 highlights the relationship between direction of wave approach and wave heights. Although the most frequently occurring waves are from the south (Table 4.3), the largest waves are approaching from an easterly direction. This also supports Figure 4.16. Wave heights over the study period did not exceed 4 m in height.

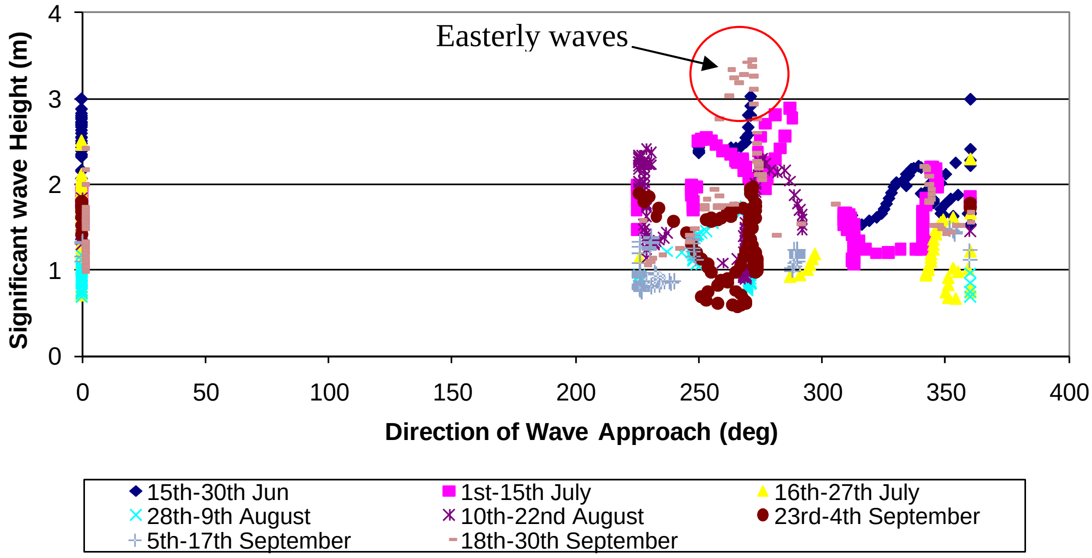


Figure 4.17 Direction of wave approach and wave heights. The x-axis shows degrees of wave approach from north (0).

It appears that the wave periods from each direction of wave approach were relatively consistent over the study period in the range of 6 to 10 s, as shown by Figure 4.18.

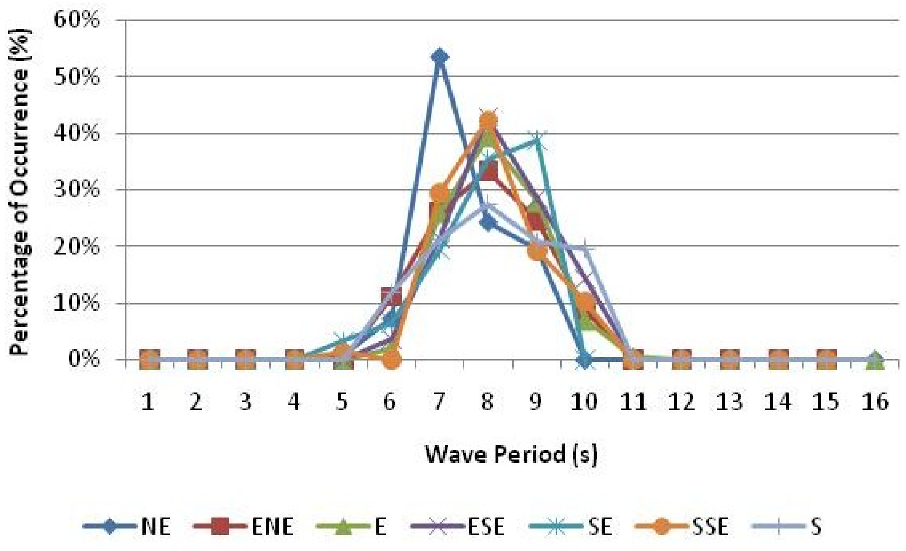


Figure 4.18 Wave periods for each of the wave approach directions. July to September 2009.

Refer to Appendix C for a breakdown of wave heights between each field visit. Due to the different timescales each data set represented the data could not be amalgamated. To get around this issue the 28 years of wave data was broken up into three sets of nine year periods; 1979 to 1988, 1989 to 1998, and 1999 to 2008. This revealed interesting results in average wave heights. Between the years 1979 to 1988 the average wave height was recorded to be 1.16 m. The wave height between 1989 and 1998 had increased to approximately 1.24 m. This was an approximate increase by 0.08 m. Between 1999 and 2008 the average wave height had risen again to 1.41 m which was an increase by approximately 0.17 m. The average wave height over the three month study period in 2009 was recorded to be 1.57 m. This represented an increase in average wave height of 0.16 m since the 1999 to 2008 period. Since 1979 the average increase in wave height was approximately 0.13 m which equals an increasing wave height of 0.004 m yr^{-1}.

Figure 4.19 represents the average daily significant wave heights that occurred up to the 10 m depth contour at Motunau Beach. This figure clearly shows fluctuating wave heights between 1 to 3.5 m across the three month period. Motunau was characterized by a relatively consistent wave height of 1.57 m punctuated by sporadic larger events with variable durations. For example, a high wave event with moderate duration observed on the 22nd June, approximately one week prior to the initial shoreline profile.

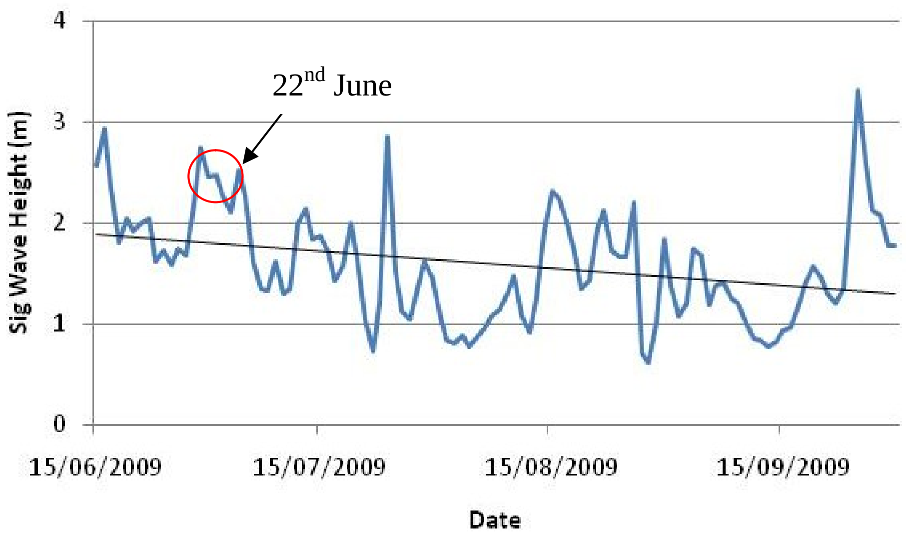


Figure 4.19 Offshore significant wave heights from the 15th June to the 30th September 2009. Trend line reveals a gradually decreasing average daily wave height.

For a further breakdown of average wave approach directions, wave heights, and periods between each field site visit refer to Appendix B.

4.7 Chapter Summary

The wave climate at Motunau Beach is limited by the orientation of the coast line. This orientation favours the occurrence of a northerly and southerly wave climate. Southerly waves appear to be the most frequently occurring as the dominant southerly swell refracts up the east coast of the South Island and continues northwards. These findings indicate that the wave climate offshore of the Motunau promontory is similar to the rest of the east coasts. The processes of wave refraction around Banks Peninsula to the south of Motunau, suggest wave heights are significantly reduced and therefore it the easterly waves that can be associated with larger wave heights. The average wave height has increased from 1.16 m between the years 1979 to 1988, to 1.24 m between 1989 to 1998, and then again to 1.41 m between 1999 and 2008. In 2009 this average wave height had increased again to 1.57 m. These results could indicate an increasing significant wave height over a longer period of time which would have serious implications on the shoreline morphology at Motunau Beach. It is the high-frequency and low-magnitude wave climate that influences the shoreline morphology on a regular basis.

Chapter Five

Long Term Shoreline Morphology

5.1 Introduction

The previous chapter gave an in-depth look at the wave environment around Motunau Beach. This is important for the analysis of sediment transport directions and identifying potential areas where local residents might expect wave focusing or shadowing. Chapter Five employs GIS techniques to examine changes that have occurred in Motunau since the 1950s. These techniques have been used to measure fluctuations in the level of sediment along the beach and include; the use of aerial photograph comparisons to compare long-term change, along with shoreline profiles on Sandy Bay. Figure 5.1 outlines the locations of the five shoreline profiles that were measured at two week intervals during the study period. This figure indicates the location of the debris slump and cliff tension crack. These two features were regularly measured in order to gauge and quantify a rate of change. Appendix D contains coordinates for their positions.

Figure 5.1 Location of the shore profiles used for the July to September study period. Aerial photograph sourced from www.linz.govt.nz.

5.2 Historical shorelines at Motunau

Figure 5.2a reveals that Motunau was relatively undeveloped at the time the aerial photograph was taken in 1950. Property development atop the cliffs had not yet occurred. It appears that the land was in the process of being subdivided prior to a development boom. This photograph reveals little or no manipulation of the river mouth had occurred by people. At this time the holiday homes were still present on Sandy Bay in the shadow of the cliffs at the eastern end of the bay.

Figure 5.2b reveals a vast difference in the level of property development by 1968. This photograph was taken prior to the first reference to instability in the 1970s. Housing had developed along the top of the cliffs and also on the lower river terrace in mid photograph. Vegetation plantings along the banks of the river are more distinguishable giving an indication of either aesthetic use or an attempt to stabilise the levels of natural river channel adjustment and avulsion.

Figure 5.2c (1980) was taken after the time the erosion of the river bank at the mouth of the river first became a problem. As mentioned in Chapter Three a formal report was lodged in the 1970s. It is clear that the land use on the promontory had intensified. The promontory had to adjust to a larger population level as well as an increased level of boat traffic in the lower reaches of the river channel. The level of unvegetated sand in Sandy Bay appears to have increased around the middle of the bay, suggesting a possible phase of sand accumulation or beach adjustment.

Figures 5.2d and 5.2e are taken two years apart (1993 and 1995) and reveal the channel guides that were built at the mouth of the Motunau River. The extent of the sand dune system on Sandy Bay appears to have changed since the 5.2c (1980s) photograph. There are also clear changes in the position of the cliff line adjacent to the river mouth. A sewage treatment pond, in the upper-mid section of the photograph, was built between 1980 and 1993 to accommodate the demand of increased infrastructure.

Figure 5.2f from 2004 is the most recent aerial photograph available for Motunau Beach. It reveals little has changed in the way of manipulation of the river mouth. Water depths are no longer able to sustain the mooring of multiple vessels near the bend in the river, as was the case in Figure 5.2c (1980). Subdivision of the section of land atop Sandy Bay is beginning to occur.


a: 1950


b: 1968


c: 1980

Figure 5.2 Aerial view of the Motunau Beach study site from 1950 to 2004. Aerial images 1968 to 1995 sourced from Andrew Woodward, ECan archives, 2009.

The previous images highlight just how constricted the main settlement at Motunau has become since the 1950s. The township is situated on a section of land between the coastline and the Motunau River (Figure 5.3).

Figure 5.3 View looking west across the Motunau Township (2008). Main access road to the jetty and parade is visible mid photograph. Eroding sea cliffs are on the far left. Jetty and first bend in river are to the right of the photograph just out of shot.

Figures 5.4 and 5.5 display the historical shoreline at Sandy Bay and historical cliff line position from 1950 to 2004. A series of historical aerial photographs have been superimposed over the most recently available aerial image taken in 2004. The average root mean square value (R.M.S) from the six images is 1.82337 m (Appendix E).

Figure 5.4 reveals that between the years 1950 to 1968 there was a maximum loss of beach width around 25 m. After 1968 it appears there were only smaller-scale fluctuations in the level of beach erosion. It can be clearly seen that the most drastic loss of beach width occurred closer to the cliffs at the eastern end of Sandy Bay. The ends of the beach remained relatively stable.

Figure 5.5 reveals that between 1950 and 1968 there were only minor fluctuations in cliff line retreat and this continued up until 1980. This finding also agreed with the rates of cliff loss discussed by R.W. Morris and Associates (1987). Between the years 1980 to 1993 there was a loss of cliff line in the range of 10 to 23 m. From 1993 to 2004 there was a continued loss in the range 5 to 16 m. This equals a maximum rate of cliff loss between 1980 and 2004 at around 39 m. This rate is likely to be greater given the 2008 erosion of the cliff and the smaller-scale cliff collapses between 2008 to recently. These have not been included in the recent calculations due to a lack of a current aerial photograph and lack of measurements. This image highlights the key area of cliff loss which is at the end closer to Sandy Bay.

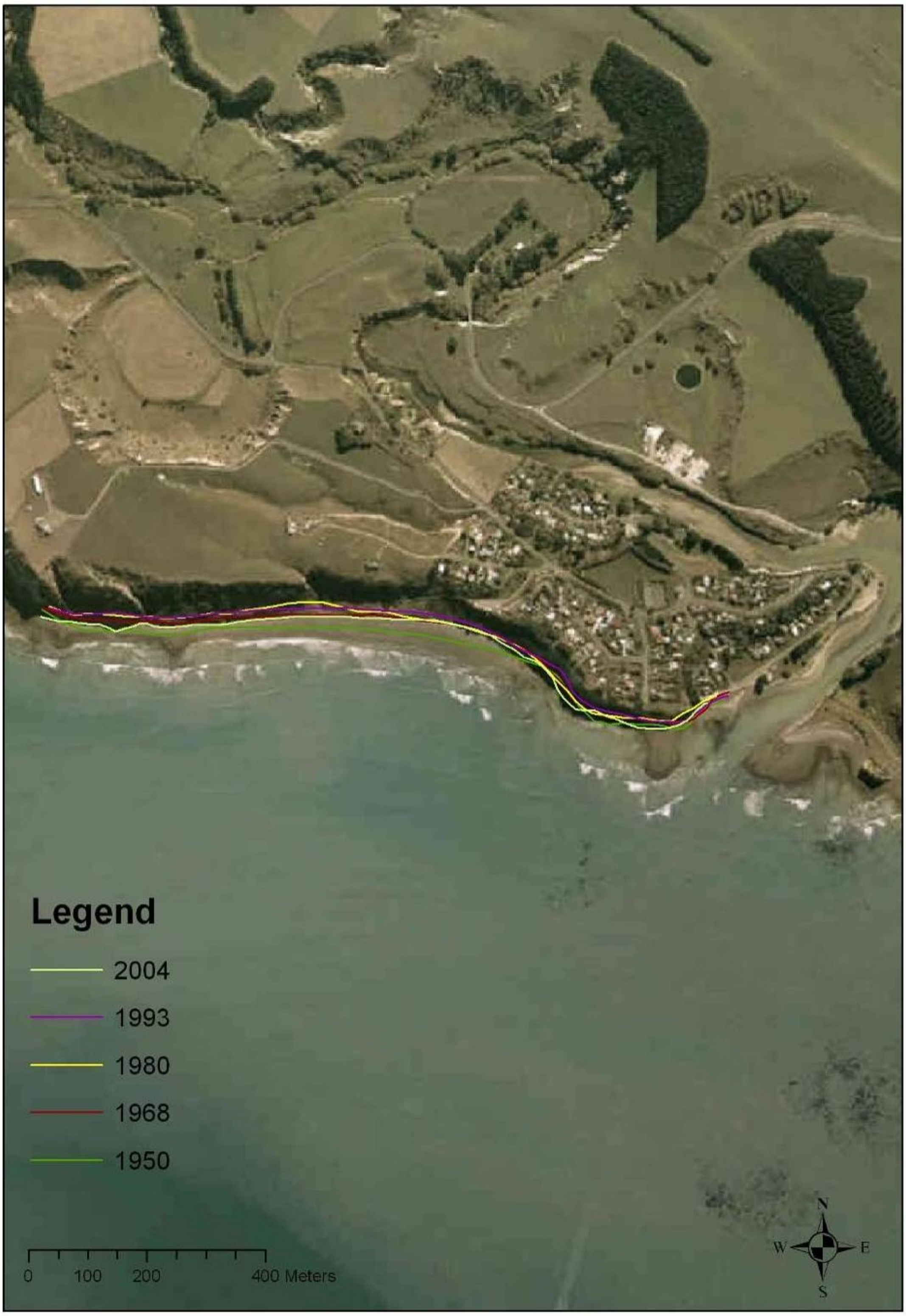


Figure 5.4 Historical shoreline positions of Motunau Beach 1950 to 2004 determined using aerial photograph analysis and superimposed on the 2004 photograph. Aerial image sourced from www.linz.govt.nz.

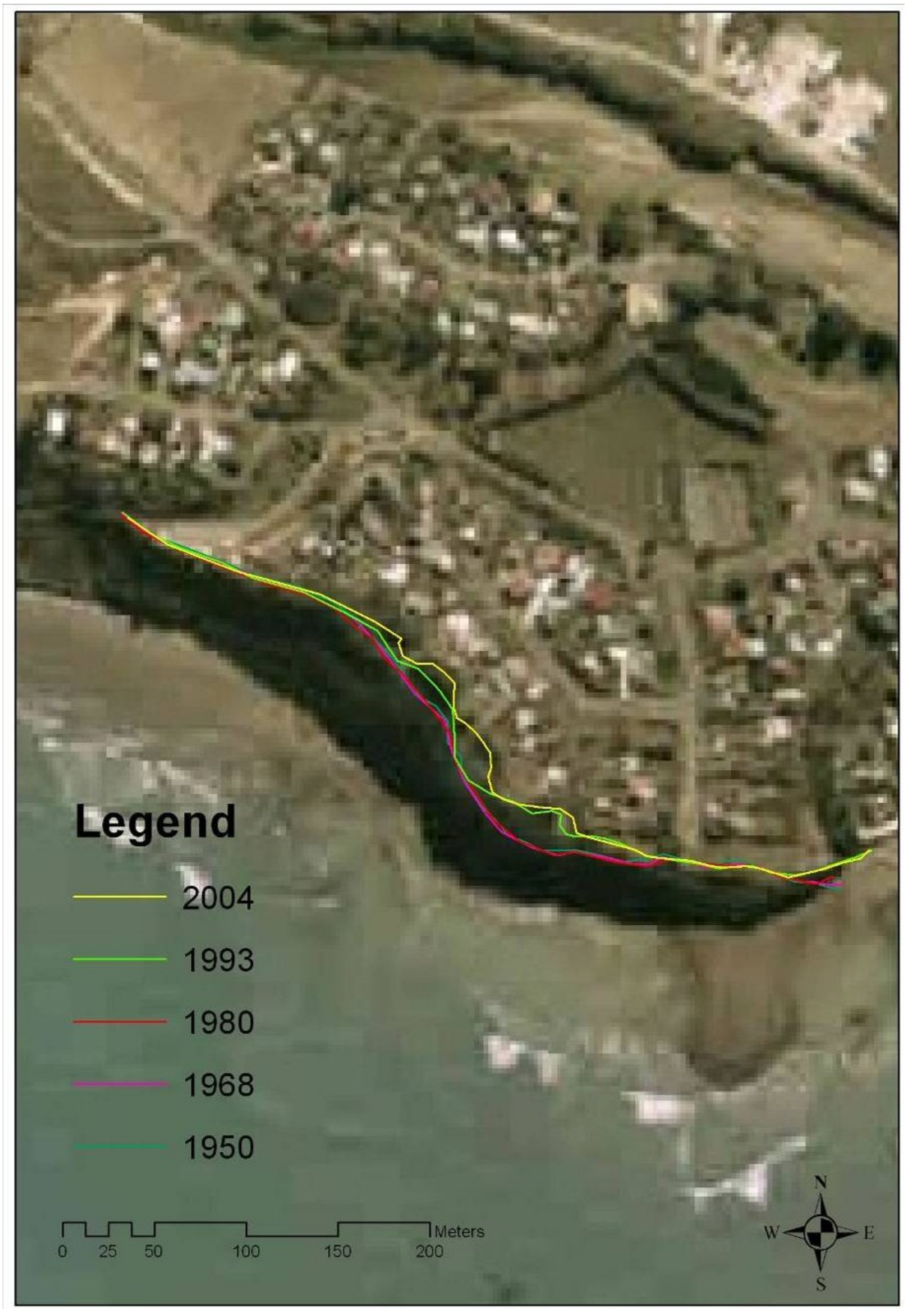


Figure 5.5 Historical cliff line positions of Motunau Beach 1950 to 2004 determined using aerial photograph analysis and superimposed on the 2004 photograph. This image is of the eastern end of Sandy Bay closest to the Motunau River mouth. Aerial image sourced from www.linz.govt.nz.

5.2.1 Section Summary

- Prior to the 1950s Motunau was characterized by a lack of significant property development.
- Between the years 1950 and 1968 there was a maximum reduction in beach width of 25 m.
- Between the years 1980 to 2004 there was approximately 39 m of cliff retreat.

5.3 Motunau Beach Shoreline Morphology

The Sandy Bay profile three (SB3) is positioned at the western end of Sandy Bay and reveals small fluctuations in the level of beach sediment in the range of 0.2 to 0.5 m (Figure 5.6). This profile represents a low gradient beach which suggests it significantly dissipates wave energy prior to the waves reaching the gravel and driftwood layer. The profile shows a net gain in sediment over the period July to September 2009. The response of this profile to wave energy appears to be relatively uniform across the length of beach. The left side of the figure represents the front erosional scarp of the historical dune system. The horizontal distance between 40 m to 110 m is the section of the shoreline which is dominated by gravels and boulders related to the rockshore platform.

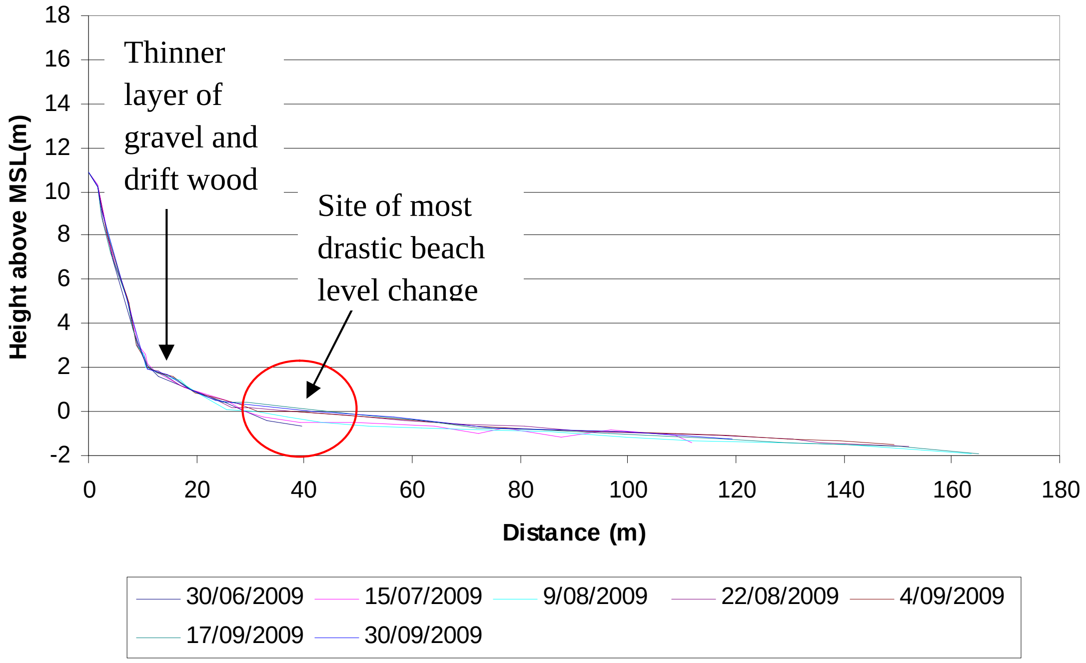


Figure 5.6 SB3 profile

Figure 5.7 represents the elevation changes across the SB3 profile throughout the July to September study period. This figure indicates where the greatest amount of change is occurring along the shoreline. The contours appear to respond consistently across the profile showing a net accumulation of sediment. There was survey error on the 27th July. Therefore, the hashed line represents inferred data between the 15th July and the 9th August. Figure 5.7 indicates that at approximately the 40 m contour the profile experienced the most drastic fluctuations in the rates of sediment accumulations and loss. The 10 m contour remained relatively stable throughout due to the coarse sediment sizes associated with the gravel beach and drift wood indicated in Figure 5.8.

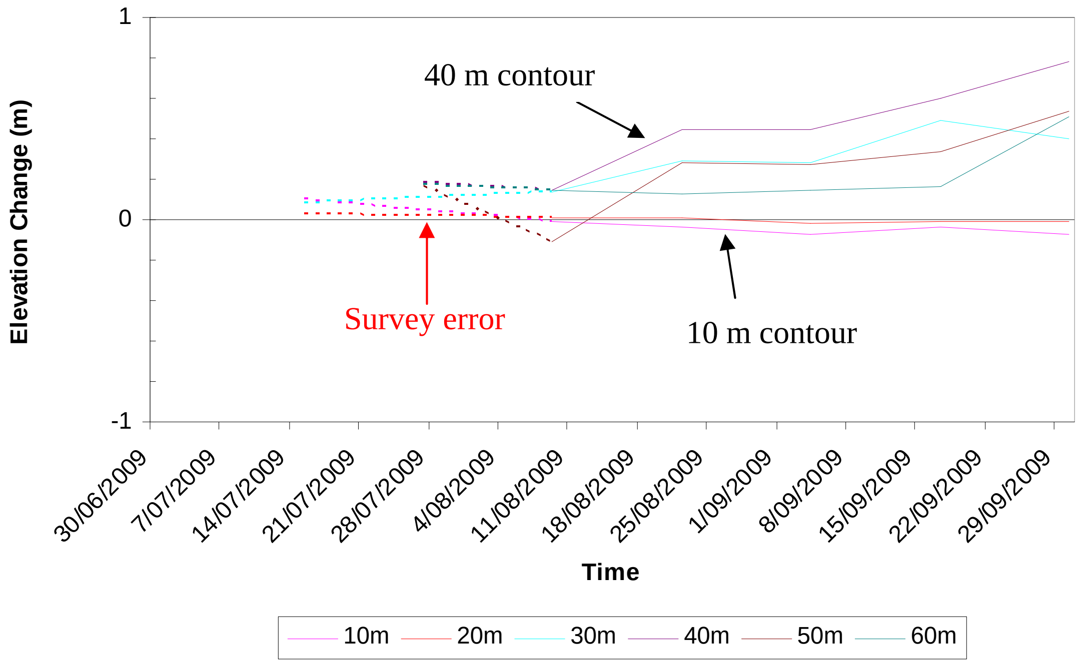


Figure 5.7 Plot of elevation changes at different contours. Hashed line represents inferred trend due to survey error on the 27th July 2009.

Figure 5.8 Slope of erosional scarp at base of eroding historical dune system towards the western end of Sandy Bay. Note the thin layer of drift wood and the thin gravel beach. Photograph taken early July 2009.

The Sandy Bay profile two (SB2) is located in the centre of the bay and was expected to show the most drastic fluctuations in sediment levels over the study period (Figure 5.9). At the beginning of the study this profile appeared to be in a net loss of sediment from the beach in the range 0.2 m to 0.5 m. From the 27th July it deposited vertically by a maximum of 0.5 m. As of the 9th August the profile continued to deposit material up until the 22nd August by a maximum of 0.5 m. It then appeared to stabilize through to the end of September (Figure 5.10). This profile also appeared to respond to wave energy in a uniform pattern despite the smaller fluctuations in the level of the beach sediment around 0.2 m. Figure 5.10 represents the elevation changes across the SB2 profile throughout the study period. At approximately the 60 m contour the beach showed the greatest range of beach adjustment. The 10 m showed the least amount of adjustment due to the size of material on the upper beach associated with the gravel beach and drift wood deposits (Figure 5.11). This profile appeared to gain sediment across the length of the beach profile throughout the study period.

The gradient of this profile suggests it also significantly dissipates wave energy prior to it reaching the upper beach section and the foot of the sand dunes. The abrupt slope to the left of the profile represents the erosional scarp at the base of the historical dunes (Figure 5.11). The horizontal distance between 30 m and 120 m is characterized by the dominance of sandy material with very little occurrence of gravels or boulders.

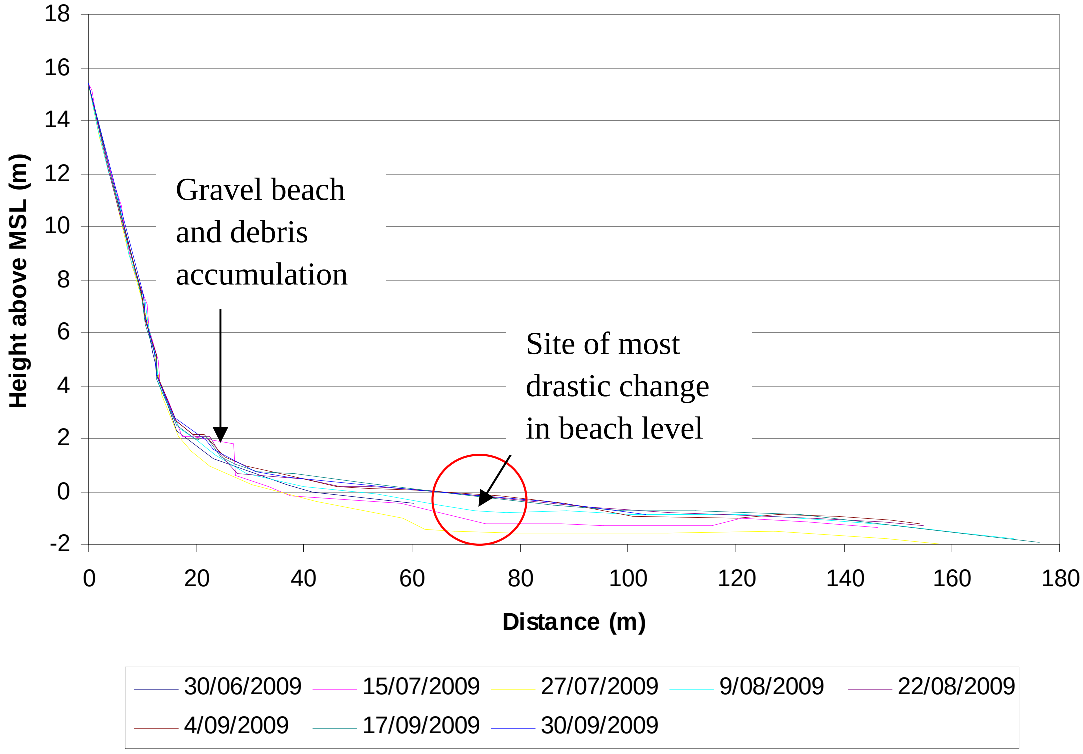


Figure 5.9 SB2 profile

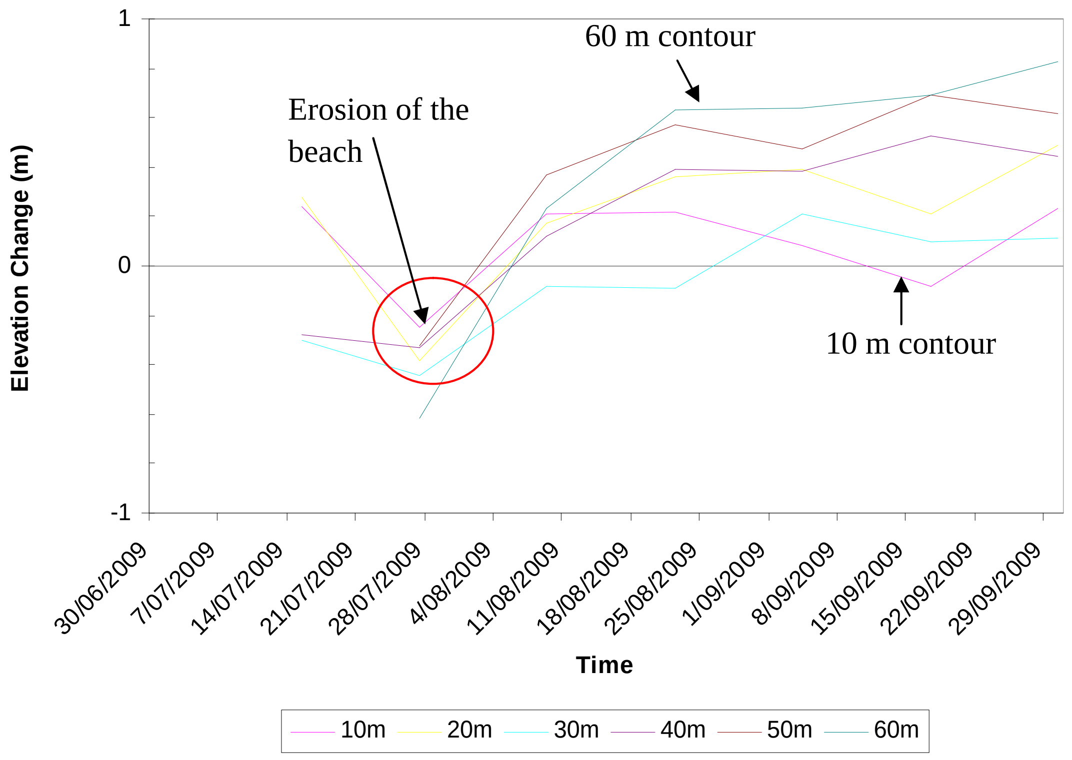


Figure 5.10 Elevation changes along the SB2 profile

Figure 5.11 Upper beach profile at SB2. Photograph taken late June 2009.

The Sandy Bay profile one (SB1) was also characterized by fluctuations in sediment levels in the range of 0.2 m to 0.5 m (Figure 5.12). The low beach gradient supports the dissipation of wave energy. There appeared to be a level of accretion by approximately 0.2 m between the surveys 30th June to the 15th July. This was followed by an erosional event. From the 27th August there appeared to be a relatively steady state of erosion and accretion up until the end of September. The left of the profile represents the erosional scarp of the historical dune system. This slope is more vegetated in comparison to the previous profiles. The upper limit has had a high level of human interference in the past due to presence of an old swimming changing shed (Figure 5.14).

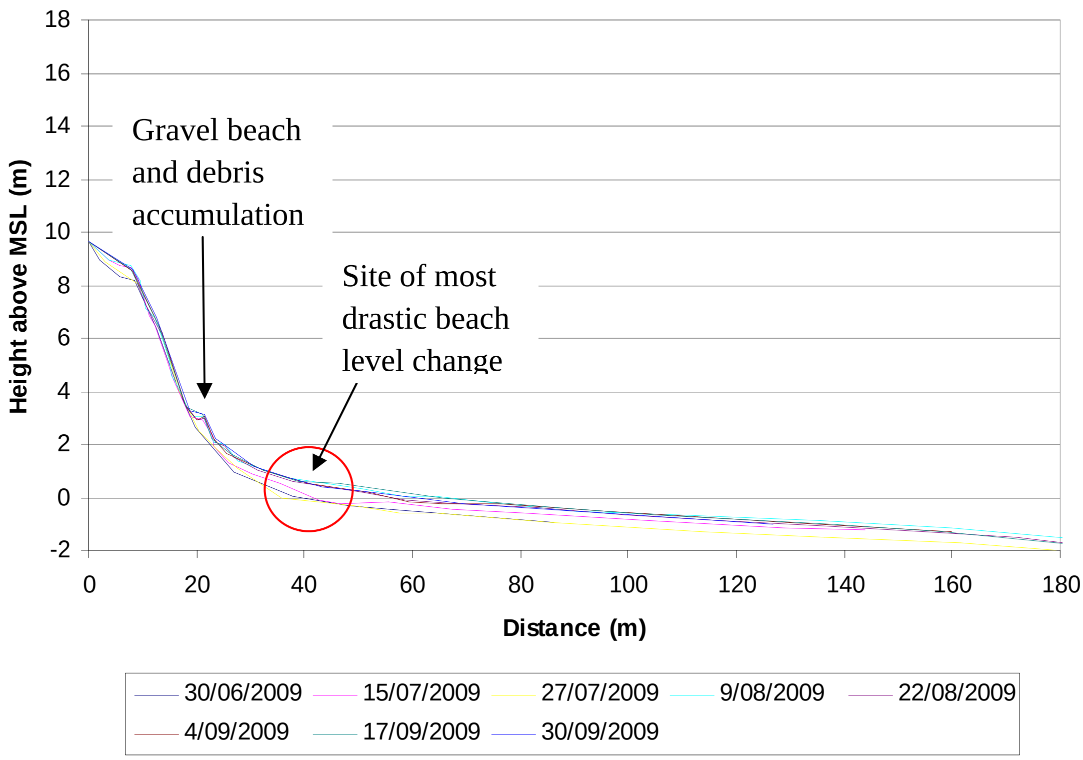


Figure 5.12 SB1 profile

Figure 5.13 represents the elevation changes across the beach profile. It was at the 40 to 50 m distance that the profile experienced the greatest changes in sediment levels. The 10 m contour remained consistent due to the coarser sediments associated with the gravel beach and drift wood deposits. The profile also appears to show a trend of net deposition.

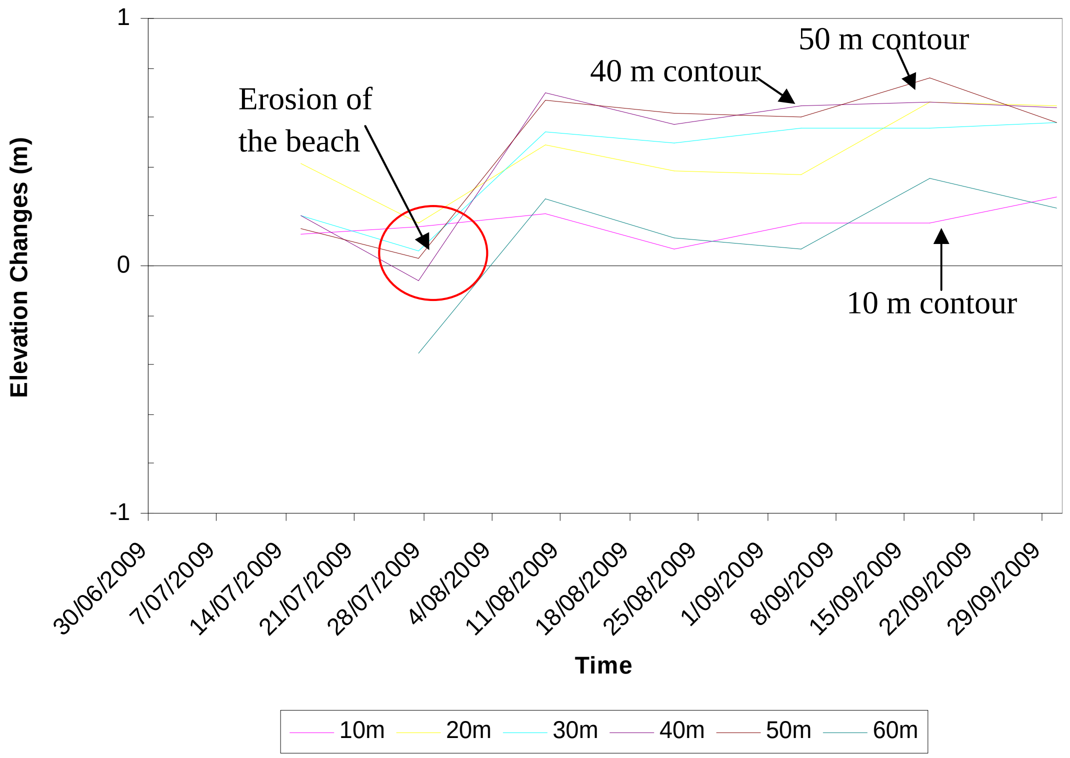


Figure 5.13 Elevation changes along the Sandy Bay one profile

Figure 5.14 Old changing shed in the dunes at profile SB1 situated 10 m above MSL. Photograph taken July 2009.

The ECan profile H2458 remained relatively stable indicating no net deposition or erosion up until the 27th July (Figure 5.15). Following this the profile deposited vertically by 0.5 m up until the 9th August, and then there was a net loss of material across the profile up to the end of the study period. This process is indicated in Figure 5.16. The left of the profile indicates the erosional scarp of the dune system. The profile starts at 40.9 m because originally it was surveyed from the top of the car park. Due to growth of a pine tree it has obstructed the theodolites line of sight. The same parameters have been repeated in order to fit the regional council's methods so that these surveys can be continually reproduced in the future.

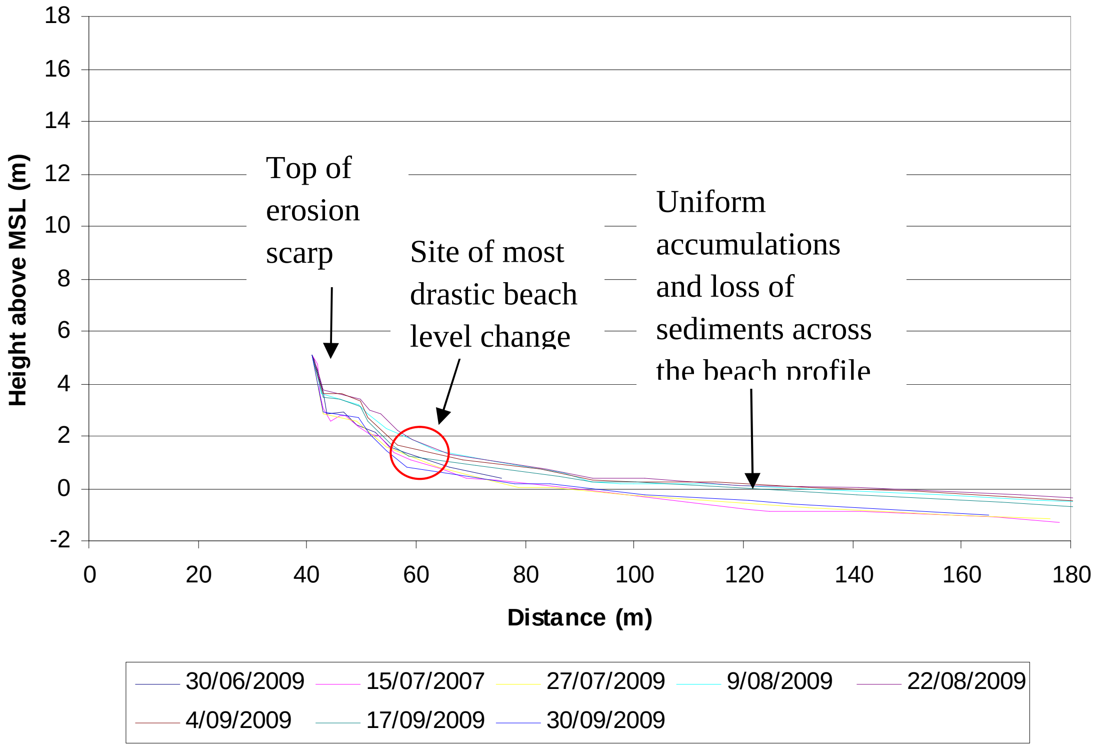


Figure 5.15 Sandy Bay profile ECan H2458

Figure 5.16 represents the elevation changes across the ECan H2458 profile. It appears there is a uniform response of sediment to wave energy. The low gradient favors the dissipation of wave energy. At approximately the 50 m contour the beach was exposed to the greatest amount of sediment deposition and removal. The 40 m contour remained stable throughout the study period as it is elevated above wave contact. These findings are also supported by field observations outlined in Appendix B. This loss of sediment from the eastern end of the beach did not fit initial assumptions. The gravel beach deposit along with the driftwood and debris deposit is approximately 14 m in width at this end of the beach (Figure 17).

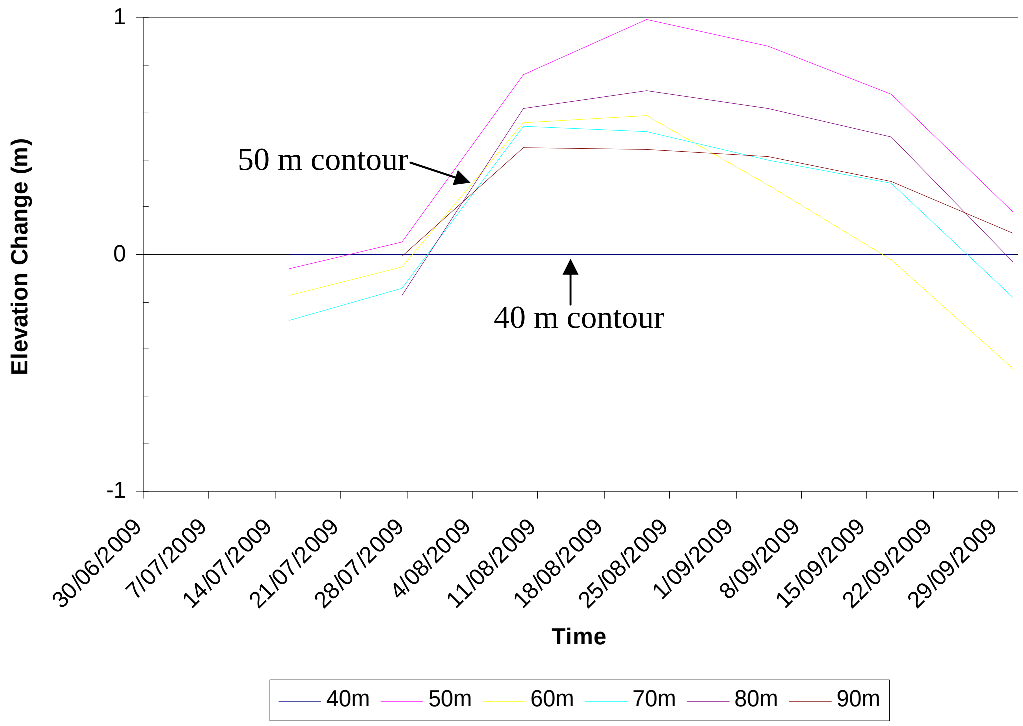


Figure 5.16 Elevation changes along the ECan H2458 profile

Figure 5.17 Example of the beach slope towards the eastern end of Sandy Bay at ECan profile H2458. Note the width of the gravel deposit and driftwood deposit. Photograph taken late June 2009.

The Ecan profile H2554 lies at the mouth of the Motunau River and is located further east than the previous profiles situated on Sandy Bay. This profile is both in the lee of the eroding coastal cliffs as well as in the lee of Sandy Bay. This profile does not contain the same slope characteristics and resembles a concave profile due to its channel form (Figure 5.18). The left side of the profile indicates the car cark. The abrupt incline on the right of the profile represents the precast concrete blocks which make up the channel guide.

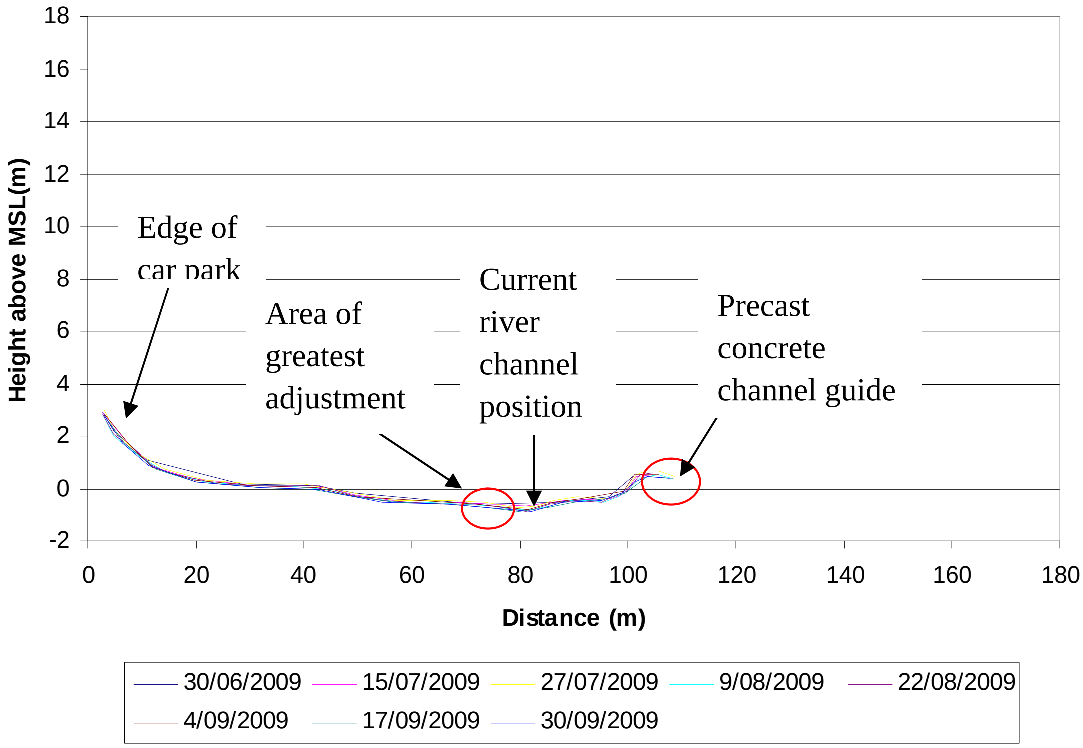


Figure 5.18 Motunau River Mouth profile ECan H2554 from the 30th June to the 30th September 2009.

This profile has showed very little change in bed form and adjustment to flow regimes (Figure 5.19). There are small-scale adjustments in the range 0.1 m to 0.2 m in the active channel which is situated approximately 70 to 80 m from the car park. Over the study period the active channel appeared to lower its bed level by approximately 0.4 m and then remain relatively stable. This limited adjustment is potentially due to the coarse characteristics of the material in the river channel being less responsive to flows, both from the river and flood and ebb tidal phases (Figure 5.20). The hashed line represents survey error on the 27th July so data has been inferred between the 15th July and the 9th August.

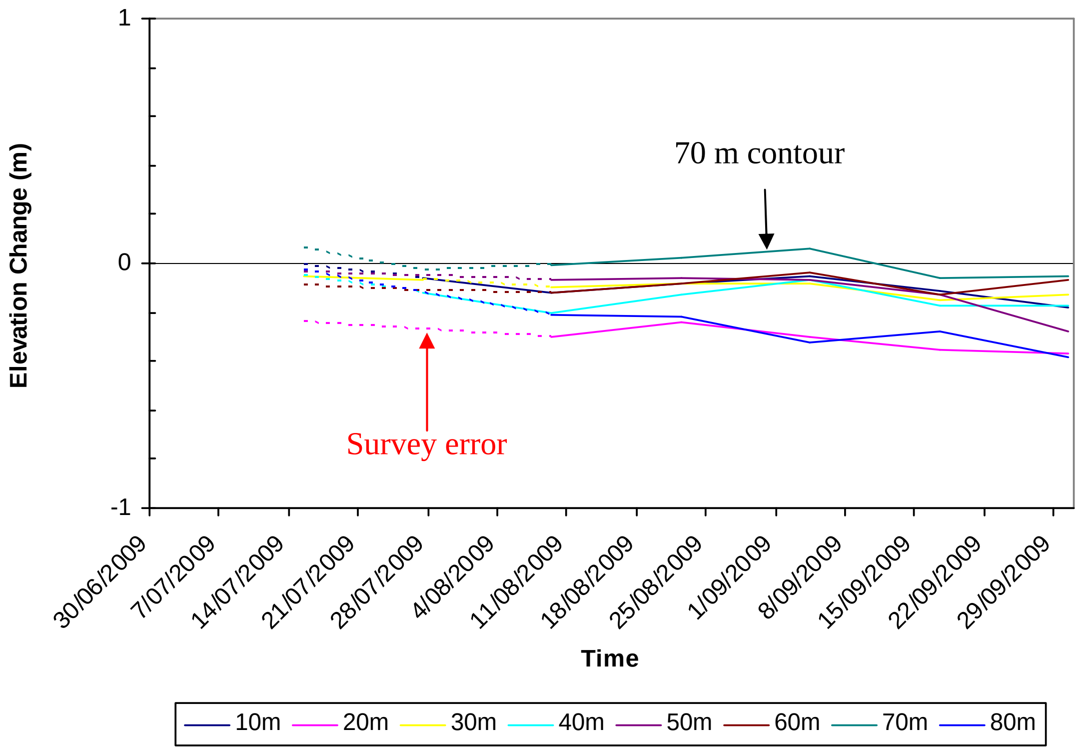


Figure 5.19 Elevation changes across the ECan H2554 profile. Hashed line represents inferred data due to survey error around the 27th July 2009.

Figure 5.20 Example of the river bed morphology at profile ECan H2554. Note the coarser material at the edges of the channel with finer sands in the middle. Photograph taken 26th July 2009.

5.3.1 Section Summary

- Low gradient beach dissipates wave energy.
- Common range 0.2 to 0.5 m of sediment adjustment.
- Uniform responses in sediment adjustment across each profile.
- Spatial variation in sediment volumes across the length of the beach.
- All profiles responded to an erosional event between the 15th July and the 9th August.
- SB2 showed the greatest variations in sediment levels.
- There was less sediment adjustment at either end of the beach.

5.4 Beach Volume Changes

Figure 5.21 represents the volumes of sediment above mean sea level (msl) at each profile from July to September 2009. The profiles SB2 and SB1 experienced the most drastic alterations in the net volumes of sediment between msl and the profile pegs located in the sand dunes. ECan H2458 and SB3 are similar in terms of their net volumes of sediment which is due to their positions on the opposite edges of the bay. ECan H2554 appears to be relatively stable throughout the study. For a further breakdown of these changing profile volumes refer to Appendix F and G.

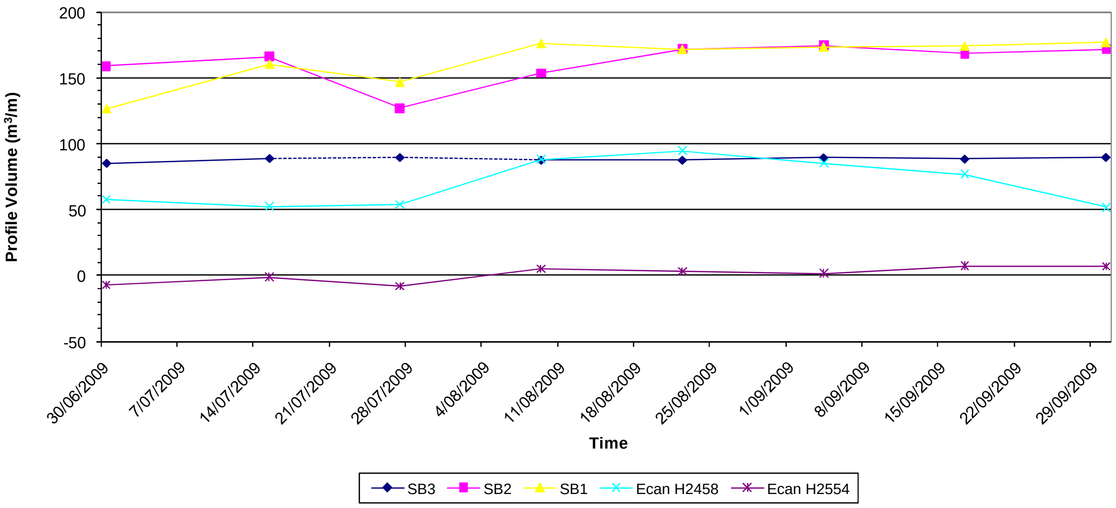


Figure 5.21 Profile volume changes from the 30th June to the 30th September 2009.

Figure 5.22 indicates the total volume of beach sediment present during each site visit. This was estimated by multiplying the single profile, representative of 1 m of beach, by the distance halfway to the neighbouring profile. SB2 has the largest net sediment volume across the beach. The beach appears to have responded to an erosional event around the 27th July signifying erosion and loss of sediment volume at each profile. The river mouth profile was excluded as was not part of the beach system on Sandy Bay. For a further breakdown of these results refer to Appendix G.

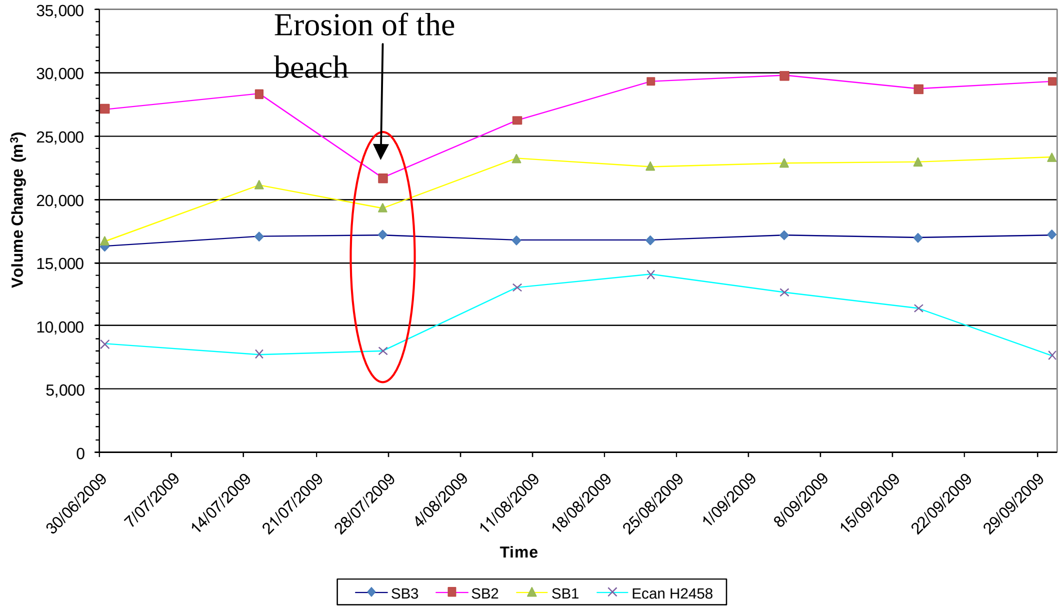


Figure 5.22 Total profile volumes of beach sediment on Sandy Bay 30th June to the 30th September.

Figure 5.23 indicates the changing envelopes of sediment volumes at each profile from the 30th June to the 30th September 2009. This figure shows the response of each shoreline profile relative to one another. This is a depiction of overall beach adjustment during the study period and suggests that there is spatial variation in response to wave energy across the beach. For a breakdown of the wave energy prior to each survey refer to Appendix I. All profiles across Sandy Bay showed a clear loss of beach sediments in late July. This is also supported by Figures 5.21 and 5.22. The erosion around the 27th July was followed by a depositional sequence and then a net loss of sediment volume from each profile. SB3 and SB2 responded differently at the end of September and began to accumulate sediment. There were a series of smaller fluctuations in sediment volumes for the remainder of the study. The response of the beach indicated in Figure 5.23 is also dependent upon the different morphologies. SB3 shows very little gross volume change over the three month period which is due to the rock shore platform base limiting the amount of vertical lowering during storm events. SB2 shows the greatest dynamics in the volume of sediment and appears to respond slightly slower to wave energy and change in late August. Profiles suggest this is relatable to the large quantity of sediment in comparison to the other profiles. SB1 also reveals beach level fluctuations in response to the different wave energies. In contrast to the previous three profiles ECan H2458 appears to lose sediment at the end of September. Figure 5.23 shows although there are links between profiles across the beach in relation to wave energy response, there are some trends that require further investigation, such as the response of H2458 to wave energy.

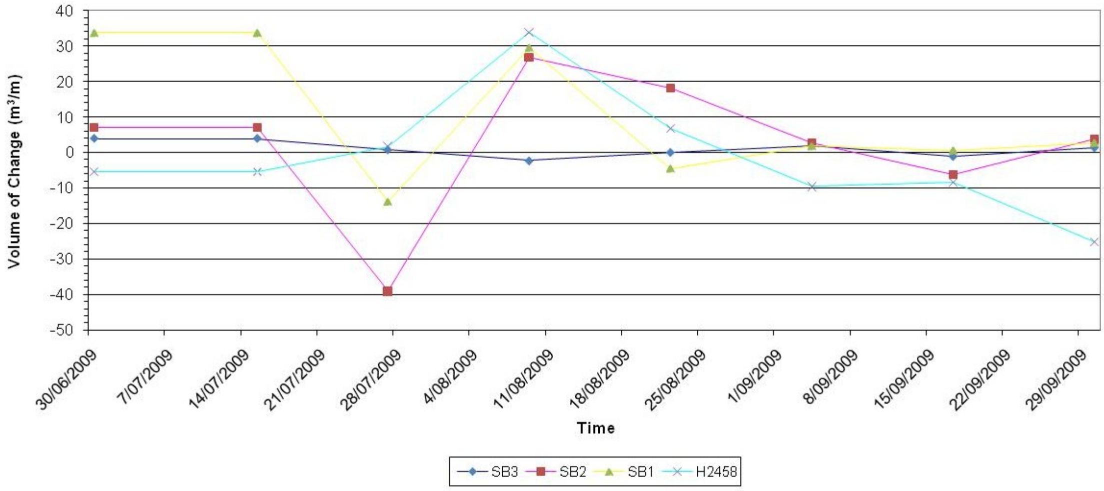


Figure 5.23 Volume changes of each profile across the study period 30th June to the 30th September 2009.

Table 5.1 indicates the envelopes of change between each survey period. These changes are in relation to the volume of sediment, above msl, that were observed on the 30th June 2009. From these changes a net volume was configured, indicating the spatial differences in sediment responses to wave energy. Refer to Appendix H for a breakdown of wave energy prior to each survey.

Table 5.1 Envelopes of sediment volume change from the 30th June to the 30th September.

Date	30/6/09	15/7/09	27/7/09	9/8/09	22/8/09	4/9/09	17/9/09	30/9/09	
Profile	Profile volume (m^3/m)	Volume Changes (m^3/m)							Net volume (m^3/m)
SB3	84.84	+3.92	+0.75	-2.27	+0.05	+2	-1.04	+1.34	11.37
SB2	158.88	+7.09	-39.09	+26.72	+18.15	+2.63	-6.3	+3.67	103.65
SB1	126.64	+33.81	-13.88	+29.62	-4.47	+1.85	+0.64	+2.74	87.01
H2458	57.61	-5.39	+1.75	+33.90	+6.67	-9.56	-8.43	-25.08	90.87
H2554	7.09	+5.72	-6.82	+13.30	-2.14	-1.4	+5.7	-0.33	35.41

5.4.1 Section Summary

- SB2 and ECan H2458 showed the greatest adjustments in volumes of sediment change. However SB2 and SB1 contained the greatest profile volumes of sediment.
- SB3 and ECan H2458 show a greater similarity in profile volumes of sediment however are different in the net volumes of sediment.

5.5 Debris slump and tension crack measurements

In order to gauge the level of wave influence at the base of the coastal cliffs a small debris slump at the junction of the cliff base was regularly measured. Table 5.2 represents the changes in the slumps total volume over the three month period July to September. Estimates of slump volume suggest that it was reduced by 332.4 m^3 over the three month study period. From observations this has occurred from the combined influences of wave attack and subaerial weathering (Figure 5.24).

Table 5.2 Change in volume of the debris slump over the three month study period July-September

Site Visit	Dimensions (m)	Total Volume (m^3)	Volume Change (m^3)
30/6/09	9 x 2.8 x 17	428.4	
15/7/09	6 x 3 x 17	306	122.4
27/7/09	5 x 3 x 17	255	51
9/8/09	6 x 3 x 16	288	33
22/8/09	5 x 3 x 15	225	63
4/9/09	5.2 x 3 x 16	249.6	24.6
27/9/09	6 x 3 x 16	288	38.4
30/9/09	6 x 3 x 16	288	0
Total:			**332.4**

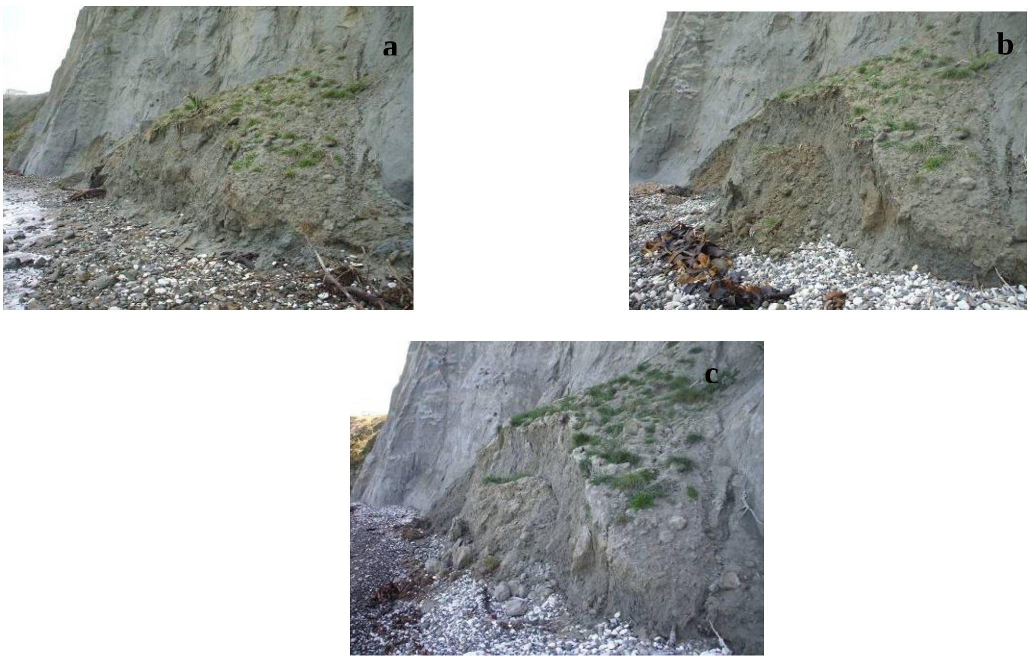


Figure 5.24 a) Photograph taken July 2009. b) Photograph taken mid August 2009 shortly after the smaller erosion event occurred. Evidence for wave attack is the kelp at the base. c) Photograph taken September 2009.

In combination with the measurements of the slump at the base of the cliffs a large tension crack was located atop the cliffs and regularly measured (Figure 5.25). This crack was situated next to the site of the most active cliff erosion, as indicated previously in Figure 5.4. According to Andriani and Walsh (2007) if shore parallel fractures are present it is often a sign failure and collapse is imminent.

Figure 5.25 a) the crack atop the cliffs, b) notice a property boundary fence to the left. Photograph taken prior to study period in late June 2009.

A series of pegs were installed and regularly measured at intervals of two weeks (Figure 5.26). Table 5.3 represents the changes in distance between each site visit for each of the three peg sets. No significant change in the distance between the pegs occurred throughout the study period. Smaller variations in the range of 2 to 3 mm between the pegs can be attributed to natural peg adjustment in the ground or recording error. When the pegs were being initially installed a historical set of pegs used for the same measurement were found. The pegs were installed in the late 1980s by Barrell (1989) for his study of cliff failure (Figure 5.27). These pegs give a relative age of this crack in that it was still present during the late 1980s. During that time there was a series of cracks present. From Barrell’s methods it is hard to decipher accurately which crack is the one still present in 2009. The current small timescale study was not long enough to record any change or seaward movement of the cliff edge.

Figure 5.26 a) measuring crack distance number 3 after stakes had been installed. b) Measurement was taken from the outside edge of the stakes. Photograph was taken 29th June 2009 beginning of study period.

Table 5.3 Distance between each of the peg sets throughout the 3 month study period were as follows;

Date	Peg 1 distance (mm)	Peg 2 distance (mm)	Peg 3 distance (mm)	Peg 4 (Barrel 1989) distance (mm)
30/6/09	71.4	78.4	50.4	79.7
15/7/09	N/A	N/A	N/A	N/A
27/7/09	71.4	78.4	54.0	79.7
9/8/09	71.4	78.3	54.0	79.0
22/8/09	71.5	78.5	54.0	79.5
4/9/09	71.3	78.5	54.0	79.5
17/9/09	71.2	78.5	54.3	79.5
30/9/09	71.5	78.5	54.4	79.5

Figure 5.27 Location of Barrell's (1989) small steel tube pegs. The existence of such pegs gives a rough indication of the age of this crack and the rate of movement. Photograph taken in late June 2009.

5.5.1 Section Summary

- The debris slump was subject to a combination of subaerial weathering and wave attack resulting in a volume change of 332.4 m^3
- No significant variation in the tension crack occurred

5.6 Wave refraction analysis

The refraction analysis of a 2 m high and 10 second wave around the Motunau promontory has revealed differences in the distribution of wave energy at the shoreline. For each prevailing wave direction a 2 m high 10 second wave was refracted towards the shoreline (Appendix H). It was calculated that for waves with these dimensions the wave length, or distance between consecutive crests, would be approximately 156 m and travelling at a velocity of approximately 15.6 m s^{-1}. This revealed differences between southerly waves and northeasterly waves in terms of wave energy modification by the bathymetric contours. This consequently affects the amount of wave energy received at the shoreline and effects on shoreline morphology.

Figure 5.28 is a 2 m high 10 sec wave approaching the promontory from the northeast. It appears the wave orthogonals generally travel shore-parallel down the coast seaward of the 30 m depth contour. This finding fits the depth of dividing contour calculation of approximately 23 m. This means that once the wave gets to a water depth of approximately 23 m the water particle motion, as discussed in Chapter Two, begins to be affected by the bathymetry. As the wave reaches the contours linked to the Motunau promontory, a rapid bending of the wave crest towards the shoreline occurs. This bending happens as the wave crest tries to align itself parallel with the shoreline, as discussed in Chapter Two. This results in the dispersal of wave energy along the coast over a wider area. Ultimately this means that with northeasterly waves we should expect relatively low-energy wave events with little or no erosion of the shoreline morphology. The dispersal of wave energy should be associated with sequences of sediment deposition along the beach and in the nearshore zone at Motunau. Figure 5.28 also indicates how hard it is to accurately depict the wave processes between Motunau Island and the shoreline. The refraction and resulting dispersal and converging of wave orthogonals indicates potential sediment transport pathways. During northeasterly waves it appears there is a southerly transport of sediment occurring northeast of the promontory due to the way the wave crests are focusing the orthogonals to drive sediment transport in a southerly direction. The rapid bending of the wave crests and diverging of wave orthogonals west of the promontory suggests there are localized pockets of northerly sediment transport, as documented in Appendix B.

Figure 5.29 portrays a 2 m high 10 sec interval wave approaching the Motunau promontory from a southerly direction. This figure clearly shows the minimal effects the bathymetric contours are having on the form of the wave and its energy dispersal. The orthogonals remain evenly spaced up to the 20 m depth contour when the bathymetry starts to influence the orientation of the wave crests and energy focusing. This means that the energy these waves contain when they break near the shoreline is similar out in deeper water. This energy has obvious implications on shoreline morphology and removal of sediment from the beach. Under these conditions it would be expected that wave attack at the base of the cliffs would also increase.

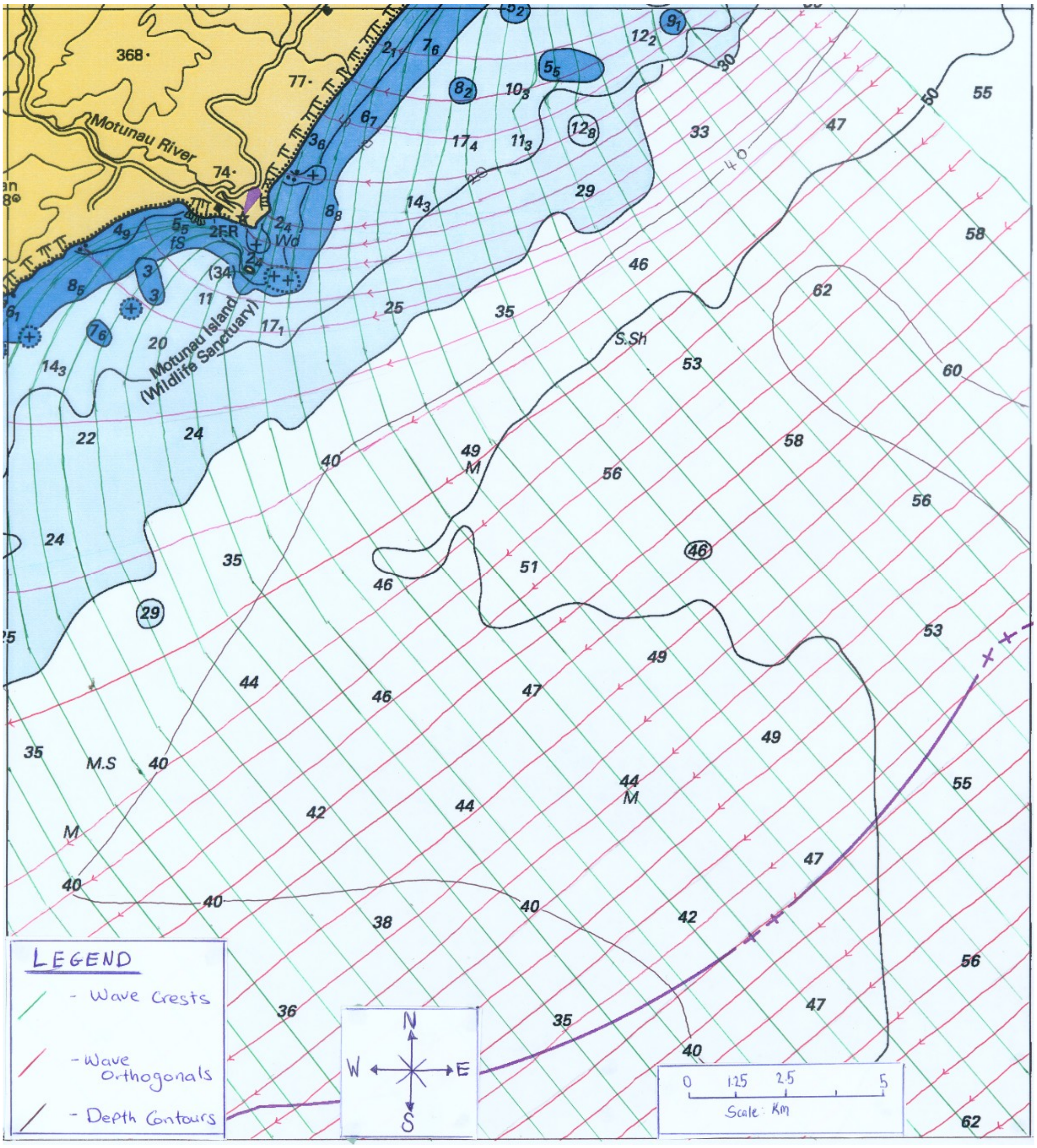


Figure 5.28 Wave refraction diagram for a 2 m high 10 sec wave approaching Motunau Beach from the northeast superimposed on hydrographic chart (sourced from www.linz.govt.nz).

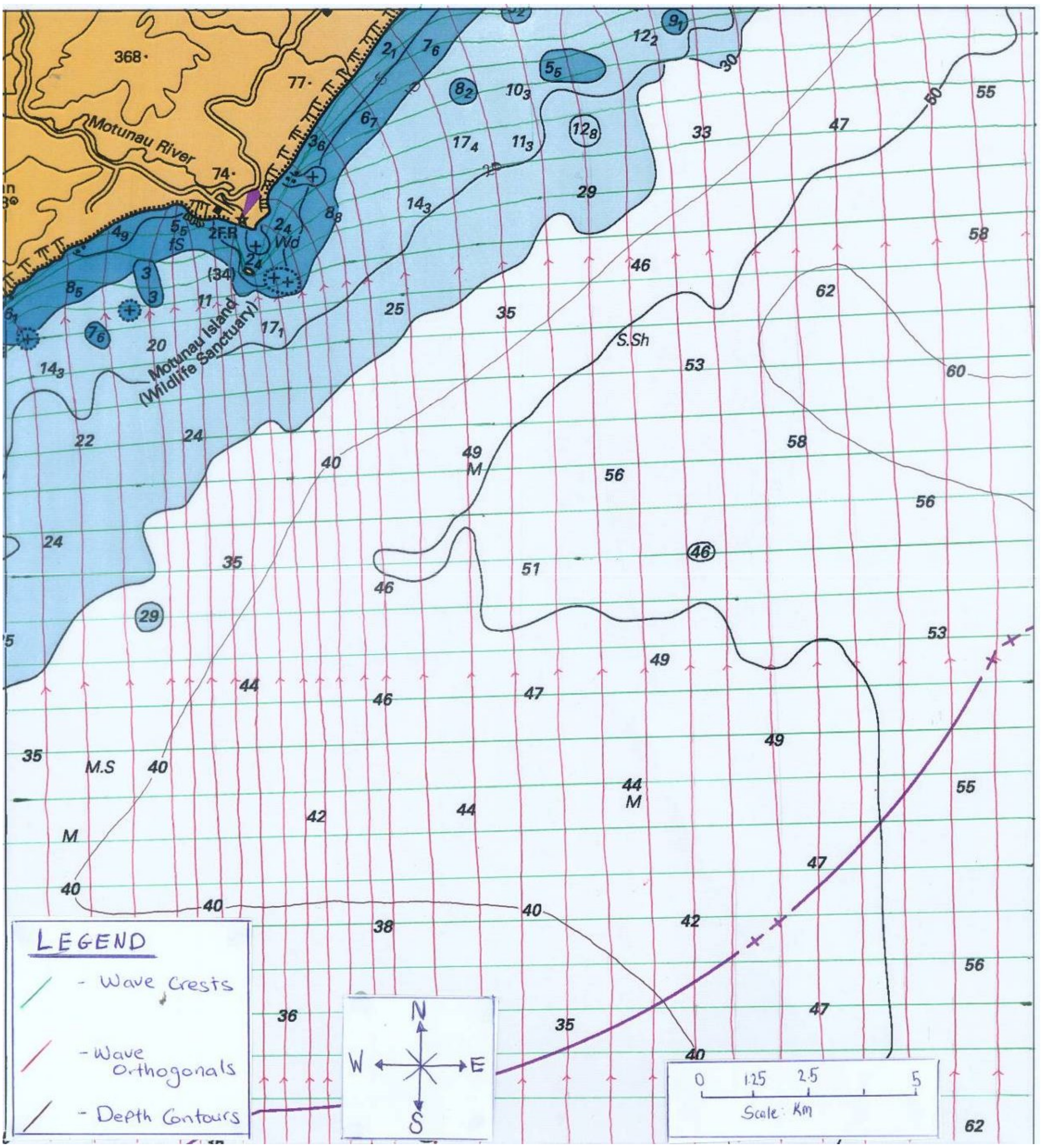


Figure 5.29 Wave refraction diagram for a 2 m high 10 sec wave approaching Motunau Beach from the south superimposed on hydrographic chart (sourced from www.linz.govt.nz).

5.6.1 Section Summary

- Depth of dividing contour for a 2 m high and 10 sec wave is approximately 23 m.
- Northeasterly waves are associated with divergent wave orthogonals due to the processes of wave refraction by the bathymetric contours. This results in lower wave energy.

- Southerly waves are less affected by the bathymetric contours therefore there is a greater deep water wave energy received at the shoreline.

5.7 Chapter Summary

The results suggest temporal and spatial variations in the rate of shoreline change since the 1950s. These results indicate that there are a series of high-frequency sediment mobilisations which are within a longer seasonal trend of shoreline response to wave energy. Sandy Bay exhibits variable zones of sediment erosion and accumulation possibly as a direct result of wave energy associated with the variable wave climate of the nearshore zone at Motunau. Shoreline profiles across the promontory reveal individual zones and response rates to wave run-up. Over the three month study period there was a net gain of beach volume on Sandy Bay. This trend however was punctuated by high energy wave events which resulted in the removal of sediments from the beach profiles. Southerly waves have more of an effect on shoreline morphology due to the direct influence of wave energy onto the shoreline. This is because the waves are less refracted and modified by bathymetric controls.

Chapter Six

Discussion

6.1 Introduction

Chapter Six will elaborate on the results presented in Chapter Five and tie these findings into the broader international context of coastal literature as discussed in Chapter Two. This chapter will interpret and explain the field observations from the July to September study period. In doing so, this chapter answers the initial research questions that were used to guide this research. The first research questions to be interpreted are as follows;

6.2 What are the processes causing cliff erosion at Motunau? And is there a relationship between rock platform lowering at the base of cliffs and the retreat of Sandy Bay (increased headland effect)?

6.2.1 Aerial photographs

The analysis of the aerial photographs of Motunau Beach in the previous chapter revealed that erosion of Sandy Bay during the 1950s commenced prior to the loss of cliff. Between the years 1950 to 1968 the beach experienced a width reduction of around 25 m, equating to approximately 1.38 m yr^{-1}. This was followed by smaller fluctuations, in the range of 1 and 5 m. Initially this appears to have had little or no effect on the position of the cliff line. According to the 1987 investigation of cliff erosion at Motunau Beach carried out by R.W. Morris and Associates, there was no distinguishable difference in the cliff top position from 1894 up until 1974. From this most recent study between 1980 and 1993 it appears there was a drastic loss of cliff line in the range of 10 to 23 m or approximately 1.76 m yr^{-1}. This result agrees with R.W. Morris and Associates (1987) and also Barrell (1989). From 1993 to 2004 there was a further loss of cliff, around 5 to 16 m, or approximately 1.45 m yr^{-1}. To put these rates of loss in a national context, Gibb's (1978) study of New Zealand's 10,000 km shoreline revealed that 25 % is eroding, 19 % is accreting and the remainder is said to have shown no observable trend. The maximum amount of erosion on a cliffed New Zealand coast occurs on the south-eastern Wairarapa coast at Ngapotiki where a recorded 9.5 m yr^{-1} of retreat occurred between 1944 and 1973, or 3.05 m yr^{-1} (Gibb

1978, 1984). This rate is nearly double the rate of cliff loss at Motunau Beach. From the same study Gibb estimated average erosion rates along 44 % of New Zealand's cliffed coast range from 0.02 to 0.5 m yr^{-1}. These figures are well below the rates of loss from this study of Motunau Beach.

6.2.2 The Sandy Bay/cliff system

The following sketches (Figure 6.1) depict the formation of Sandy Bay and its cliff beach system. They were developed based on observations of the various erosional processes operating in Sandy Bay and lithologies, as well as using the cliff erosion theory reviewed in Chapter Two.

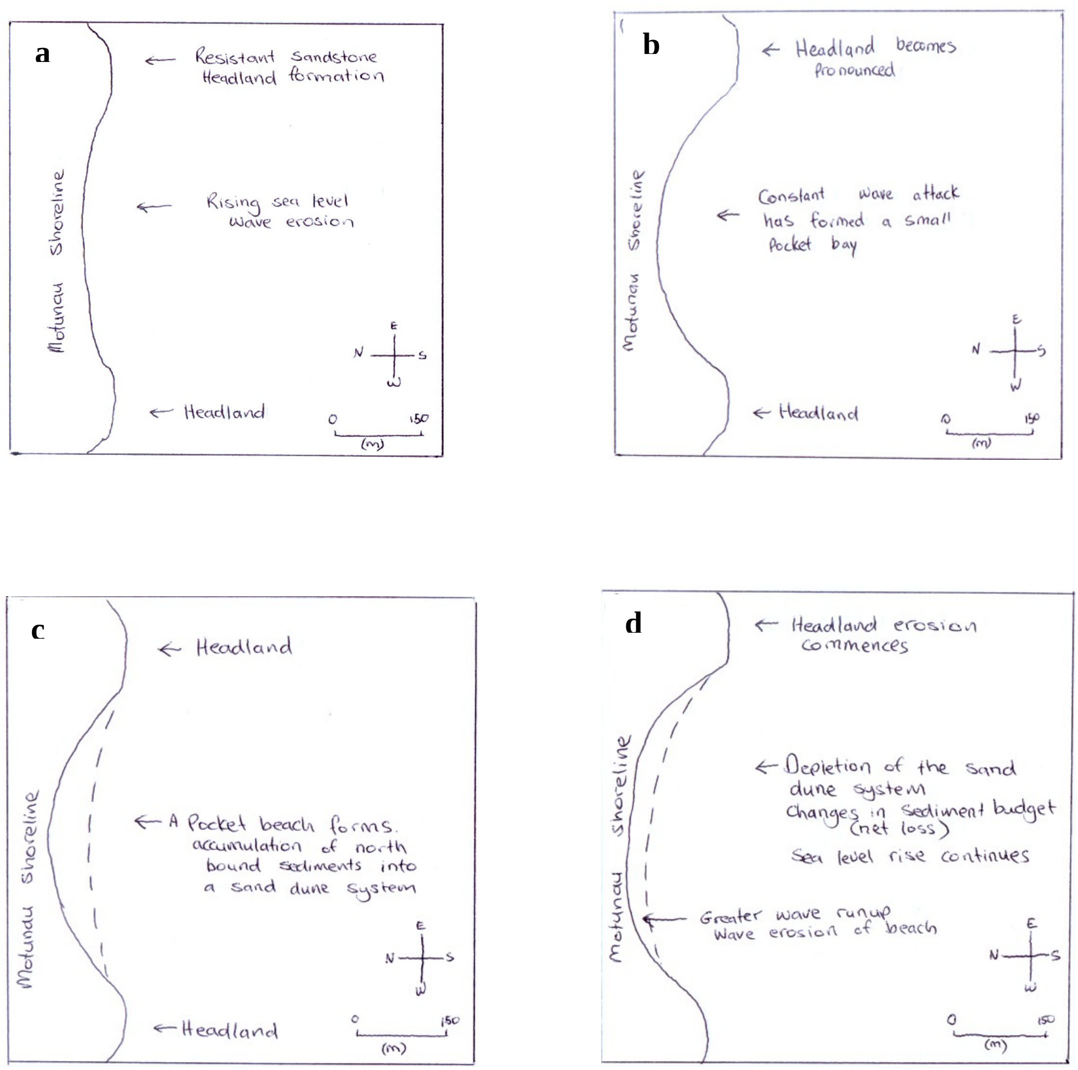


Figure 6.1 The hypothetical formation of Sandy Bay over the last 6,500 years based on field observations.

As sea level rise reached its current position approximately 5,000 yr BP the more resistant areas of sandstone cliff withstood wave attack compared to the less resistant parts. This process initiated the formation of a small bay (Figure 6.1a). Wave attack and subaerial weathering, in combination with variations in the resistance of the sandstone cliff lithology, continually modified the Motunau coast. This resulted in the resistant sandstone areas resembling pronounced headlands at either end of a small pocket beach (Figure 6.1b). Beaches tend to become shorter as bay indentation increases (Bowman et al., 2009). As sea level fluctuated over the last 5,000 years sediment, brought north from Pegasus Bay and onshore from nearshore deposits by littoral drift processes, began to accumulate in the pocket beach. This occurred because the eastern end of the beach was sheltered from wave energy and therefore favoured deposition of fine sediments (Figure 6.1c). Although the exact age and source of the sand dunes on Sandy Bay is debatable, they could represent the shoreward movement of continental shelf sands throughout the Holocene transgression (Schofield, 1970; Thom et al., 1978, 1981a/b; Hilton, 1995; Cope et al., 1998). As sea level continued to erode and degrade the resistant sandstone headlands the eastern end of the pocket beach gradually became more vulnerable to the loss of sediments via subaerial weathering and wave action. As the sediment budget on this beach changed to a net loss the wave energy began to run-up further onto the beach. This meant that accumulated sediments were more readily exposed and transported downdrift and offshore (Figure 6.1d). The photograph of Sandy Bay, taken in the 1950s (Figure 6.2), shows a foredune system that could represent another, younger phase of dune building. This is possibly associated with a more recent phase of sea level fluctuation or possibly early human settlement around the Motunau area during the early 1800s. This however is open to debate.

Figure 6.2 Location of possible younger phase of sand dune accumulation. Photograph taken in 1950, sourced from Simon Foster, 2009.

The process of beach loss highlights the lag phase that occurred between the loss of beach and subsequent cliff erosion. This cliff loss occurred because once the beach experienced a loss of width, wave energy was reaching further up the beach to the base of the cliffs (Figure 6.3). Due to the loss of the beach buffer the cliff headland would have protruded seaward, being exposed to increased levels of wave refraction and therefore wave attack. This loss of cliff is likely to further facilitate sand loss from the beach at Sandy Bay in the future (R.W. Morris and Associates, 1988). As the headland cliffs continue to erode the pocket beach will be further opened. This has implications for the sand dune system. Once the sediments stored in the sand dune system have been eroded then beach nourishment will be compromised. In the past there has been no investigation into why the beach at Sandy Bay suddenly experienced such a loss of width. A similar relationship between loss of beach width and cliff loss is outlined in Lee (2008). As discussed in Chapter Two the switching between phases of La Nina and El Nino between the years 1944 and 1946 could have been influential. This process of Sandy Bay beach loss will addressed later in this chapter.

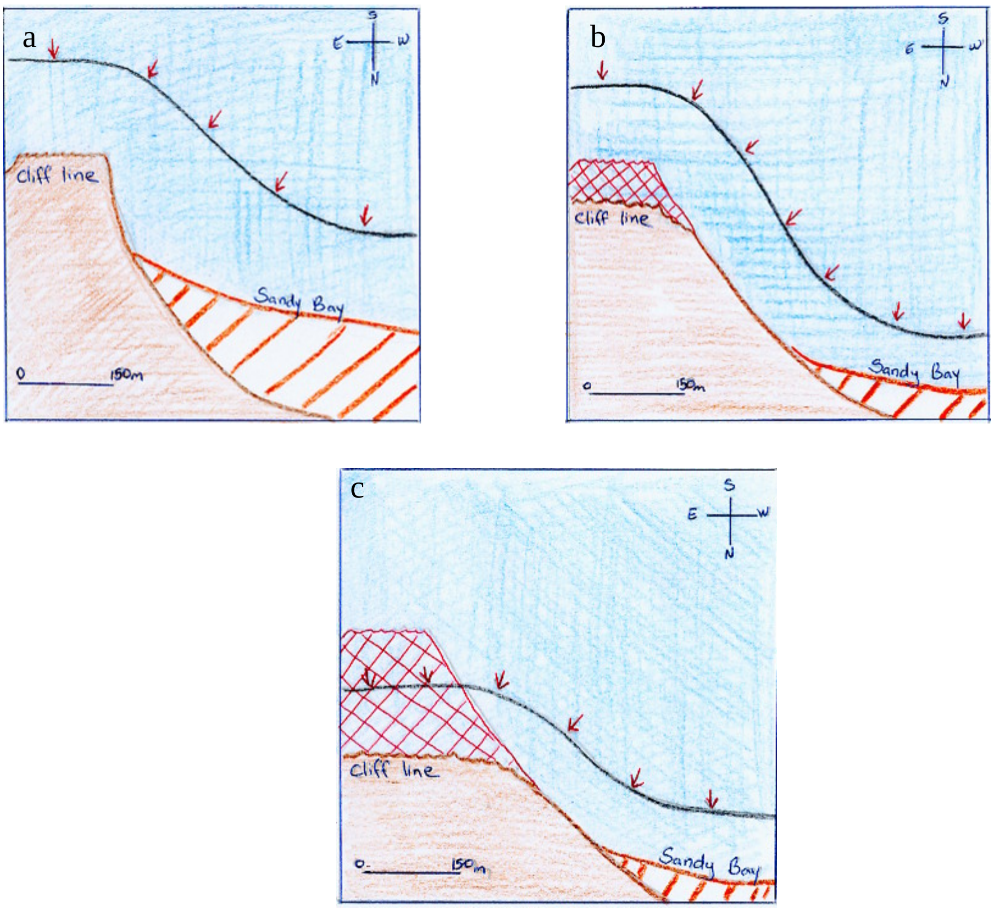


Figure 6.3 The relationship between beach width loss and cliff erosion at Motunau Beach. The black line represents a refracted wave crest; red arrows indicate the wave orthogonals or direction of wave energy. Orange areas represent sand beach deposits. The red hashed line indicates historical cliff extent.

The shoreline at Motunau exhibits a spectrum of morphologies as a result of the different types of sediment and the episodic periods of loss. The majority of the promontory appears to be relatively resistant to erosion. According to Andriani and Walsh (2007) cliff recession is an episodic and localised process which can be closely linked to storm waves. However, from the study of Motunau Beach it is apparent that there are a variety of processes leading to the degradation of the cliffs prior to the removal of material by storm waves. It is therefore appropriate to suggest that the rates of morphological change are largely controlled by spatial variations in wave energy rather than rock strength. This trend is the opposite of what appears to be occurring on the southern California coast (Benumof et al., 2000).

6.2.3 Platform Lowering

Cliff debris accumulate at the base of the cliff, as a result of subaerial weathering, and are removed rapidly by wave action. This process results in the parallel retreat of the cliff face at Motunau Beach. This means that the processes of erosion and then removal of material are in balance (Kennedy and Dickson, 2007). As the cliff has retreated it has contributed unconsolidated sediments such as boulders and gravels to the rock platform at its base. These sediments have played a significant role in the dissipation of wave energy prior to reaching the base of the cliff. They also function as an effective abrasive material on the softer sandstone base beneath the boulders and gravels. As wave action manipulates these sediments they continually move back and forth across the softer platform base resulting in the gradual lowering of the platform base at an average rate of 4 mm yr^{-1} (R.W. Morris and Associates, 1987). This ongoing widening of the platform continues as the parallel retreat of the cliffs occurs. This process has implications for the amount of wave run-up at the base of the cliff which directly influences the amount of wave energy received by the foot of the cliff. On the 13th July 2009 this process was observed around un-armoured areas of the platform. The gabion baskets that were installed in 1989 have done little to reduce the amount of down cutting of the shore platform via abrasion processes. The sandstone bed lay approximately 14 cm below the base of the gabion basket. The base of the gabion baskets would have been the active platform level in 1989. Since that time it appears that down cutting of the shore platform has occurred at an approximate rate of 15.7 mm yr^{-1}, a rate higher than was obtained in 1989. This rate varies spatially depending upon the level of sediment protection. Sediments periodically accumulate in small-scale sediment sinks providing temporary protection against abrasion (Figure 6.4).

Figure 6.4 Lowering of the rock shore platform beneath the gabion baskets that were installed in the late 1980s. Photographs taken 13th July 2009.

6.2.4 Cliff weathering

The cliff recession at Motunau Beach has been the cumulative result of interacting weathering processes as outlined in Chapter Two. These processes can be divided into first order and second order factors. First order factors are those regional scale processes such as relative sea level change or tectonics. We know that the Motunau promontory is being actively uplifted by the Motunau fault by 1.5 to 1.7 mm yr^{-1} (R.W. Morris and Associates, 1987). The second order factors are site specific features such as sediment types (Bray and Hooke, 1997). The promontory comprises consolidated siltstones, sand deposits, and gravel beach deposits, along with gravel and boulder deposits. These inconsistent zones of sediment types have resulted in the spatially and temporally variable rates of cliff recession and degradation. The responses of these sediment types to erosional processes are well documented in international literature; however, this knowledge has not previously been applied to Motunau. These processes were outlined in the cliff collapse section in Chapter Two. The stresses and strains on the Motunau cliffs, resulting from these weathering processes, have led to a variety of responses in the cliff form. There are notches, tension cracks, fractures, and debris slumps. These features are the result of long-term exposure to elements such as wind, waves, and rainfall. The upper section of the cliffs, consisting of younger beach deposits and loess, appears to be weathering at a rate separate to the lower section, which consists of an older more consolidated Greta Siltstone (Figure 6.5).

Figure 6.5 Subaerial weathering of the cliff at Motunau Beach resulting in numerous tension cracks forming. Note the way in which the top section is degrading at a noticeably faster rate that the more consolidated material below. Also note the way in which the top section appears to be leaning seaward (photograph taken 13/1/2010).

The continued weathering of this cliff has resulted in features of varying life spans. For example, debris slumps can be removed from the base of the cliff by wave action in a matter of days whereas tension cracks can be present for years before failure actually occurs. This is apparent in the case of the tension crack monitored during July to September 2009.
Although the process of cliff retreat in Motunau has been well documented since the 1970s and the mechanisms of cliff failure are understood, it is important to readdress this question in the context of longer-term coastal change. Although residents believe cliff erosion only became a problem in the late 1950s, cliffs are indicators of an erosional section of coastline, not only in New Zealand but also abroad (Bray and Hooke, 1997). What we are seeing at Motunau is the periodic acceleration of cliff collapse rates due to seasonal variations in wave climate and the level of the buffer provided by beach sediments. The rate of cliff collapse appears to have increased around the 1950s in part because the steady increase in the permanent population at this time led to the loss of the shoreline becoming more noticed and of greater threat to resident's property. The historical aerial photographs in Chapter Five show a clear sequence in the settlement of the Motunau promontory from the 1950s. It would be interesting to analyse records and historical photographs that pre-date the 1900s because it is possible a similar trend of coastal retreat occurred. Unfortunately such records do not exist.

As subaerial weathering continues to degrade the cliffs, as well as periodic wave attack, cliff instability at Motunau Beach can be expected in the future. It appears that no structural solution is going to prevent further cliff loss.

6.2.5 Section Summary

- Sandy Bay reduced in width by approximately 25 meters during the 1950s. This occurred prior to the accelerated rate of cliff erosion during the 1970s and 1980s.
- A combination of subaerial weathering and wave erosion is resulting in the parallel retreat of the cliffs. This rate is highly dependent upon the variable zones of material resulting in high spatial and temporal rates of cliff retreat and beach loss.

- As the cliff headland continues to retreat there will be a continual loss of width on Sandy Bay.
- Rock platform lowering at the base of the cliffs at approximately 1.57cm yr^{-1} is leading to the continual erosion of the cliff foot. Wave energy is less impeded therefore more energy is received at the shoreline.
- There are periodic accelerations in the rate of cliff collapse and shoreline retreat. This can largely be attributed to the seasonal nature of the wave climate and the gradual loss of the sediment buffer.

6.3 How is the bathymetry of the nearshore zone linked to changes in shoreline morphology?

From the analysis of shoreline profiles and the historical wave data, along with a review of the literature on the processes of shoreline dynamics, it is concluded that the current shoreline morphology at Motunau Beach is the result of local and non-local wave conditions. Motunau Beach is a landscape characterised by change rather than stability (R.W. Morris and Associates, 1987), largely due to the dynamic nature of the wave environment. Locally generated waves from the northeast appear to be associated with smaller-scale sediment distributions whereas the non-local waves, such as southerly swell can be attributed to the larger-scale impacts and sediment contributions to the local system.

6.3.1 Sediment transport

Historical photographs of Motunau Beach suggest there is a decreasing amount of sandy sedimentation in and around the shoreline. This decrease in sand accumulation indicates that there has been exhaustion in the amount of modifiable shallow nearshore sand supplies (Anthony, 2002). It is possible that historically Motunau was being supplied with this sandy material from an external sediment source, from the south towards Banks Peninsula and Pegasus Bay, and/or by onshore feeding from nearshore deposits. To the southwest of Motunau lies Pegasus Bay which was historically supplied by offshore deposits of sand. Currently the dominant sediment supplies to this area are fluvially sourced from the Waimakariri River, Ashley River, and the Waipara River (Cope et al., 1998). It is likely that these current suppliers of sediment inject less sediment to the coastal system, resulting in changes in shoreline morphologies downdrift. It is also likely that the tidal circulation patterns around the

Motunau promontory have changed resulting in changes to the form and orientation of the shoreline. Worldwide, coastal configurations changed considerably during the Holocene transgression, resulting in changes to tidal relationships (Kidson, 1982). As indicated in Chapter Three the process of sediment infilling of the Motunau Canyon could have potentially played an influential part in this process of coastal configuration change around the Motunau promontory. As erosion at Motunau continued wave action reshaped nearshore deposits and shoreline orientation, consequently altering the path of nearshore currents. The role of global warming on changes in coastal configuration is controversial. For example Bell et al. (2001) debates the influence of global warming on changes in ocean currents, stating that they are not affected by sea level rise alone, instead changes in wind patterns are more likely.

6.3.2 Historical sand deposits

Eddies or small localised circulations of water around the Motunau promontory could be one explanation for the deposits of sandy material around the Motunau River mouth (Figure 6.6). This historical deposit is in the lee of the eroding cliffs and rock shore platform (Figure 6.7), both of which protrude into the path of the littoral sediment transport. Sediment accumulates either side of such protrusions (Anthony, 2002). This supports the assumption that historically the eastern end of Sandy Bay did favour the accumulation of sediments prior to the increased rate of coastal erosion during the 1950s. This deposition potentially formed in conjunction with the sediment accumulations on Sandy Bay. Indicating that there is a link between the sheltering effects of the cliff headland and sand beach vulnerability. Figure 6.6 is based on examples from the literature of the effects protrusions have on sediment transport. At Motunau Beach historical deposits of sand are being eroded. The processes that deposited this sand have potentially changed as a result of continual erosion over the last 5,000 years. When the cliff headland protruded further seaward it would have favoured the formation of small current-eddies that deposited sands at the mouth of the Motunau River. As the cliffs have retreated these eddies have been dissipated by wave action which has resulted in increasing bed turbulence. This has resulted in the removal of material from the shoreline, altering the form of the nearshore bathymetry.

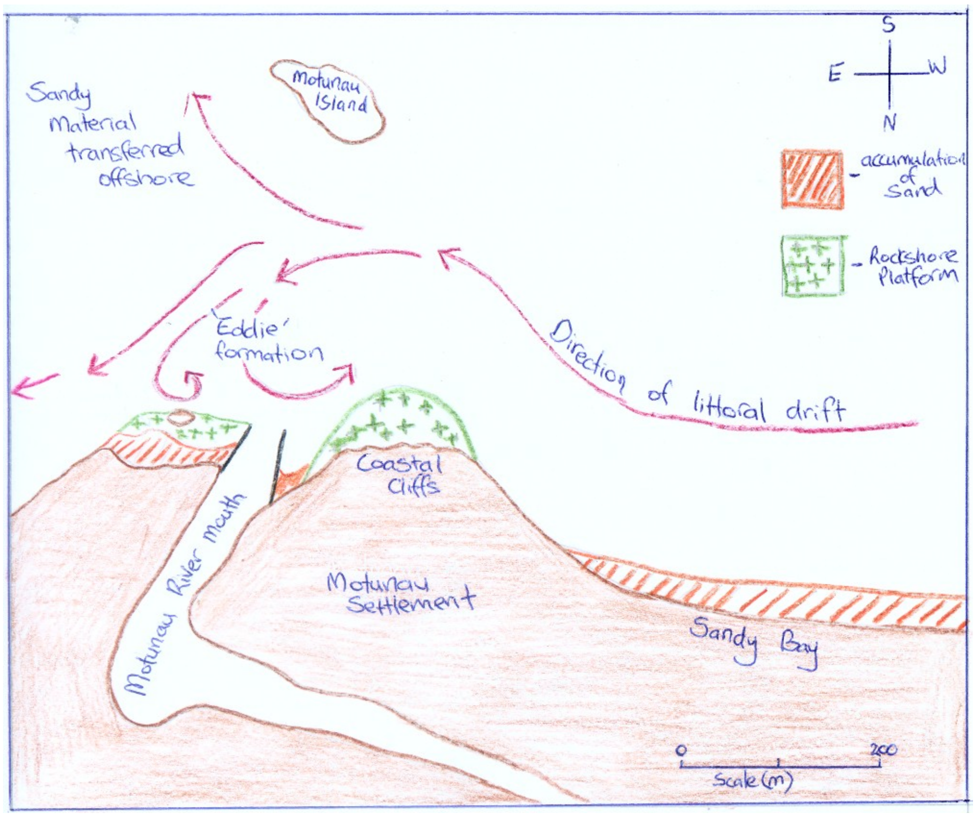


Figure 6.6 Interpretation of eddies and transport of sediment in the nearshore zone at Motunau Beach.

Figure 6.7 The historic sand dune system on the seaward side of the Motunau River mouth. Photograph taken 22nd August 2009.

The recent post-glacial sea level adjustment included both regressive and transgressive phases with heights up to 3.7 m above current sea level (Fairbridge, 1961). These fluctuating sea levels over the last 6,500 years may explain the development of the historic sand dune system on Sandy Bay (Figure 6.8). When sea level was higher the cliffs on Sandy Bay would have been active and when sea level was lower around the promontory beach width would have been greater. This would have favoured wind mobilisation of beach deposits to the back of the beach. The more recent rate of sea level rise, in the range of 1.8 mm yr^{-1}, has been more continuous (Shepard, 1963, Bell et al., 2001). This would result in a steadier rate of dune erosion and transport of the eroded material downdrift or offshore.

Figure 6.8 Historic sand dune system on Sandy Bay which is currently experiencing erosion. Photograph taken looking west 17th September 2009.

As the sea level around the promontory encroached on the shoreline sediment deposits, wave heights have increased and therefore the sediment budget has changed. Over the last 6,500 years these accumulations of sand were exposed and degraded by wave action. This transfer of sediment from the shallow nearshore zone at Motunau to the deeper offshore has lead to changes in the shoreline morphodynamics. The loss of fine sediment from the nearshore zone has meant that the underlying gravels and coarser materials are exposed and subject to increased reworking by waves and are then moved onshore by storm events. A similar progression of sediment coarsening is also outlined by Anthony (2002). This potentially explains the shoreline response and drastic loss of beach following the 1950s. Such long-term erosional trends can often be linked to insufficient sediment supplies in the nearshore (Pilkey and Hume, 2001). This also may explain the formation of the gravel beach deposit on the backshore of Sandy Bay. Evidence for this process, where fine sediment is replaced by coarser gravels, occurred at Motunau in 2008. Following a storm in August the deposit at the mouth of the Motunau River changed from being a sand bar to a gravel bar. This resulted in damage to boats.

The profiles from July to September 2009 did not reveal any drastic changes in shoreline slope or sediment levels; however, over a longer timescale, since the 1950s there has been a loss of sediment from the beach and there have been large changes in shoreline morphology. What this means is that, although we are not seeing immediate and regular large-scale losses every time a southerly storm rolls in, the beach appears to be becoming more susceptible to change due to the loss of the natural protection buffer created by sand deposits. What could be expected is that there are more regular seasonal smaller-scale cliff losses followed by large-scale collapse or change. It is possible that the headland on Sandy Bay protected the sediment levels from high-magnitude, low-duration wave events. This process was discussed in Chapter Two. The river channel it appears is still recovering from the large volumes of sediment removal that occurred during the storm in August 2008.

6.3.3 Effects of wave energy

At Motunau Beach there are large temporal variations in the amount of wave energy generated seaward of the island. From the analysis of the 20 year hindcast wave data in Chapter Four, we can see that this is not dissimilar to the rest of the east coast of the South Island. In this wider area, dominant wave approach directions are from a northerly and southerly direction, but the southerly swell dominates (Cope et al., 1998). What is interesting to Motunau is what happens to these waves landward of the 10 m depth contour as wave energy is dissipated as waves refract around Motunau Island and the shallower contours of the promontory. The amount of wave energy dissipation is dependent upon the direction of wave approach and also the wave heights. From the results it was found that there is a direct relationship between offshore wave energy and shoreline erosion, despite the processes of energy dissipation associated with Motunau Island and the shallower contours. The process whereby inshore wave heights are dependent on the offshore wave energy level is explained by Jackson et al., (2002).

Results in Chapter Five indicate that the shoreline at Motunau is not as affected by high-intensity, short-duration events. Instead modification of the shoreline occurs when high-intensity wave events continue over longer periods of time, such as a number of days. This highlights a magnitude-frequency relationship between wave energy and beach sediment loss. Wave energy in the nearshore is additionally modified by the presence of potential river deposits at the junction of the river and ocean. As discussed in Chapter Two these deposits are formed when the river flow velocity is dissipated as it reaches the sea water, favouring deposition of sediments (Figure 6.9). Deposits in the nearshore can cause the refraction and breaking of waves in water depths that would otherwise not occur (Wright et al., 1980). As the refraction maps reveal in Chapter Five, this would have implications for each of the prevailing wave directions. Southerly waves are less altered by the presence of bathymetric contours, therefore more wave energy is likely to be received by these river deposits under such conditions as compared to north-easterly waves that have been dissipated prior to reaching Motunau. This means that the form and energy of the southerly wave is more influential on shoreline morphology. This however is also dependent upon magnitude of storm waves and frequency. Locally generated wave chop is due to local wind conditions and results in short waves that are less affected by the processes of wave refraction. This local chop can approach the shore at high angles due to the shorter wave lengths. Such waves have an increased potential for inducing longshore currents due to their irregularity (Storlazzi and Field, 2000; Jackson et al., 2002). The frequent inundation and reworking of beach material by the tidal cycle results in the zonal sorting of sediments (Jackson et al., 2002). This can be clearly identified on Sandy Bay.

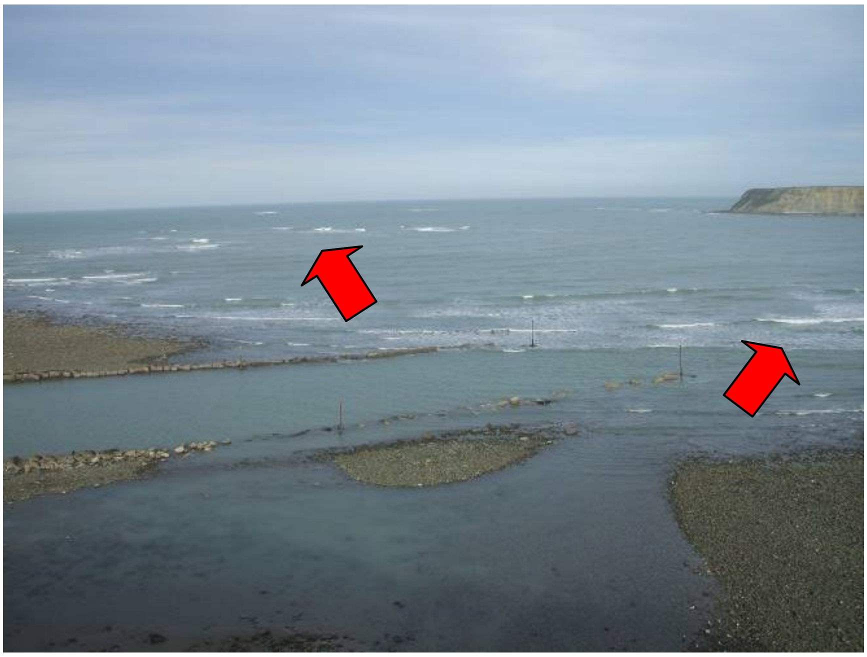


Figure 6.9 Breaking waves in the nearshore zone at Motunau Beach. On the right side of the image breaking waves are associated with possible river mouth deposits; whereas, the upper left wave breaks could be associated with other deposits in the nearshore zone. Photograph looking south on 8th August 2009.

As indicated by the results in Chapter Five there is a relationship between offshore wave energy, profile shape, and volume of sediment on the beach. This is not as clearly distinguishable as initially expected. During high wave events, such as during mid July 2009, the shoreline responded by erosion. As wave heights decreased there was deposition. Initially it was thought that due to the position of Motunau Island in the nearshore zone offshore waves would be drastically altered in size and, thus, in terms of the amount of energy. Figure 6.10 indicates that wave energy would favour the remobilisation of beach sediments. Potentially wave energy is reworking the sediments within Sandy Bay, therefore the sequences of wave energy and sediment depositions do not appear to correlate. This form of constrained sediment cycle within a pocket beach is also demonstrated by Bowman et al., (2009). The peaks and troughs of the wave heights, outlined in figure 6.10, roughly corresponded showing that around late June to early July 2009 wave heights were around 2 to 2.5 m and the profiles responded by erosion. When the wave heights decreased around the 14th July the profiles showed a depositional trend.

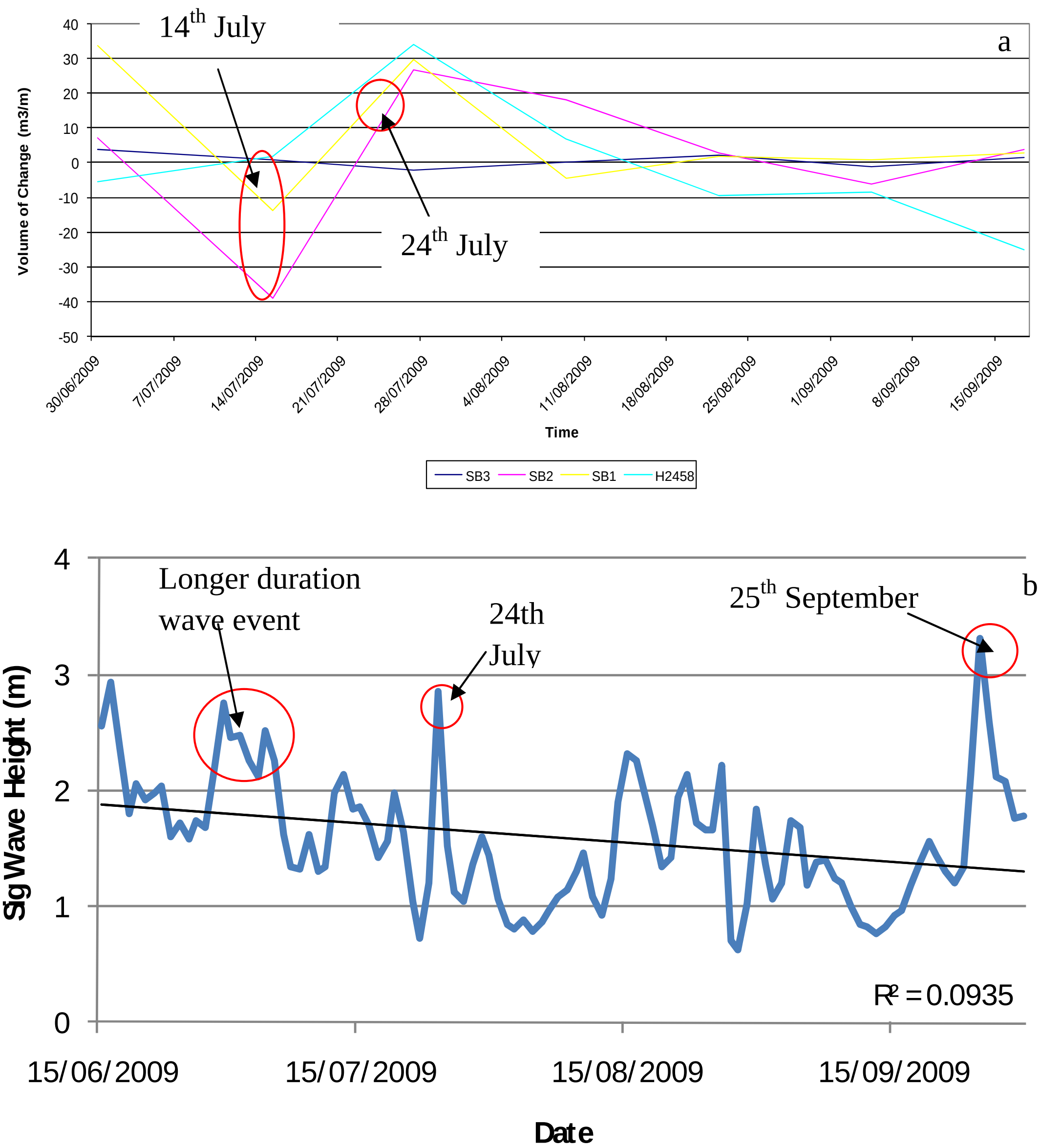


Figure 6.10 The relationship between profile volumes on Sandy Bay and wave heights at the 10 m depth contour. a) the changing volumes of the profiles along the length of Sandy Bay throughout the July to September study period. b) Significant wave heights seaward of Motunau Island from mid June until 30th September 2009. The linear trend line indicates the net decreasing wave heights throughout the study period. Data sourced from NIWA, 2009.

Figure 6.10 supports that Sandy Bay beach sediments are resistant to significant scour over short periods of time, for example a one-off high wave event, such as on the 24th July and the 25th September. Instead, beach scour is a factor of sustained intensity over a longer timescale, such as a number of days. For example, prior to the study period from approximately the 15th of June there appeared to be a prolonged period of larger wave heights. This may have caused the erosion of the sediments around the

14th July 2009. After that prolonged period, further sustained wave heights failed to occur and there was a net decrease in wave heights. The shorter duration wave events may play a role in re-mobilising sediment in the nearshore which is then moved onshore rather than transferred offshore. This may explain the irregular relationships between sediment levels on the beach and wave energy.

6.3.4 Beach sediment volumes

From the profile volume changes along the beach at Sandy Bay it appears that significant wave heights at around 2.5 m cause scouring of sediments from the beach. These sediments can be removed from the beach to form a bar in the nearshore (Dubois, 1988; Jackson et al., 2002). The exposure of the shoreline to southerly swell potentially favours the rapid scouring of sediments during storms to an offshore bar. At Motunau Beach such depositional bars have not yet been located; therefore, there is a gap in the knowledge of sediment transport in the area. The volume of sand in these nearshore sand bars may be important in the local sediment budget (Shand et al., 2001). At high tidal levels the effects of wave energy on shoreline morphology and across the platforms is greater. This is because less energy is dissipated by the shallower contours associated with the nearshore zone and rockshore platforms before the beach is reached. During medium to lower tidal levels the rock shore platforms are more significantly exposed, meaning that the pattern of wave refraction and the effects of wave energy dissipation are greater. Wave refraction patterns are altered by the rockshore platforms over variable water heights. This process is supported by the periodic deposition of fine sediments on the rockshore platform as indicated previously in Figure 6.4. This means that the sediment transport directions are also highly variable throughout the tidal cycle, as highlighted in Chapter Two, the refraction analysis, and outlined in Appendix B. One further explanation for the irregular deposits of sediments around Motunau could be related to the uneven bathymetric features associated with the promontory's contours. Contours can influence the reversibility of longshore currents and littoral drift (Frihy et al., 2004). This process can be seen at Motunau indicated by the strewn deposits of mangled wire gabion basket at the western end of the beach during prevailing northerly wave conditions.

Beaches that are on the landward side of ocean islands are sheltered from the effects of ocean waves (Jackson et al., 2002). Motunau Island changes the form and the direction of some wave crests, predominantly from the northerly sector, prior to reaching the rock platforms at the shoreline. The total effects on wave heights were not as significant as initially expected. The wave intervals and the wave velocities of northerly waves appear to be altered significantly more than southerly approaching wave crests. The beach morphology at Motunau Beach is very responsive to changes in wave energy and tidal levels which, in turn, dictate sediment characteristics. Mrs Jan Grover, a local resident of Motunau Beach stated, how quickly the beach at Sandy Bay changes, and how "it's always different" (Mrs. Jan Grover. Local resident overlooking Sandy Bay. *pers. comm.,* 13/7/2009).

6.3.5 Shoreline profiles

Observations, along with shoreline profiling along the Motunau promontory, suggest there are a series of coastal subcells. Wave refraction maps reveal variable zones of sand convergence and depletion indicating potential local sediment transport pathways. The existence of subcells means there are individual cycles of erosion, littoral transport, and sedimentation (El Banna and Frithy, 2009). The most readily identifiable subcells in Motunau are the Sandy Bay pocket beach subcell and the river mouth subcell. The beach profiles on Sandy Bay; SB3, SB2, and SB1 reveal relatively similar erosional and depositional trends. The profile ECan H2458 nearest the cliffs, however, responded differently, eroding near the end of September 2009. This erosion occurred when neighbouring profiles began to show relative stability in erosional and accretion rates. From observations of the beach profile Ecan H2458, it appeared that the sediment cover was relatively thin over the majority of the study period. This is potentially an indication of sediment starving due to higher wave energy. This means that due to the regular sandstone exposure, the eastern end of the beach is being more actively lowered due to the less effective sediment buffer. This lowering supports a greater wave run-up, favouring the modification of sediment by smaller waves.

What the profiles in Chapter Five reveal is that although there is a high level of sediment adjustment on the beach at Sandy Bay, and a direct relationship to the level of wave energy, sediment levels were operating separately from both the eroding coastal cliffs and the river mouth. This further supports the processes of a constrained onshore and offshore sediment flux similar to that outlined in Bowman et al. (2009). During the study period the average significant wave height seaward of the 10 m depth contour was 1.57 m. This wave height may have been inadequate for the transfer of material between these subcells. The idea of subcells within Sandy Bay also suggests that littoral drift or the removal or sediments downdrift between subcells is more likely to occur under high-energy or storm conditions as explained by Storlazzi and Field (2000). At Motunau these large storm events did not occur through this study period, so that this process of exchange between Sandy Bay and the river mouth was not able to be observed in action.

The ECan H2458 profile is located on the eastern end of Sandy Bay, closest to the eroding cliffs. Prior to this 2009 study, H2458 was the only profile which could have provided insight into the natural beach adjustments on Sandy Bay. However, the recent variations in sediment levels along the length of the beach demonstrate this one profile can not be representative of the entire beach. This profile recorded a net volume change of 90.87 m^3/m over the three month study period. On the 30th June this profile was recorded to have the lowest amount of sediment across the profile at 57.61 m^3/m. This indicates that this profile was limited in the amount of possible beach adjustment for the remainder of the study period. From observations, the sediment cover at this end of the beach favoured the lowering of the sandstone base beneath the sediment. That is, this end of the beach was actively being lowered at a rate faster than the rest of the beach. This finding supports ECan's efforts to continually prioritise the monitoring of this section of the beach.

The SB1 profile was closest to the ECAN profile H2458. Initially similar rates of adjustment were expected prior to the establishment of the profiles in 2009. What the profiles reveal is that the envelopes of change between profiles have been occurring in the range of approximately 0.5 m with fluctuating periods of sediment accumulation and erosion. This profile experienced at net volume change of 87.01 m^3/m between msl and the profile peg.

The SB2 profile was expected to show the most drastic rates and quantities of change prior to this study due to the obvious fluctuations in sediment levels on the beach. The profile revealed that between the 15th July and the 22nd August, vertical beach adjustments of approximately 1.5 m between profile surveys were occurring. The drastic fluctuations can be attributed to the position of this profile within Sandy Bay and its exposure to prevailing wave energy. This profile is also less sheltered by the headlands at either end of the beach and may be a site of bathymetric wave focussing.

The approximate net volume change from July to September 2009 was 103.65 m^3/m. This supports the initial observations that this site receives the most wave energy along the beach. However, due to the larger volume of sediment is less affected. This profile potentially acts as both a source and sink of sediment. During erosional events sediment is scoured and redistributed to neighbouring profiles**.**

The SB3 profile is situated at the far western end of Sandy Bay and incorporates a small section of rock platform in the mid section of the profile. The rock platform restricts the profiles natural vertical adjustment. From observations it appears that sediments accumulate upon the rocks during calm swell conditions or at slack high tide, but when the tide retreats or wave conditions are choppy the sediment is eroded exposing the rocks again. For this reason the profile exhibited a range of sediment levels. Fluctuations in the range of approximately 0.5 m occurred between profiles. Due to the morphological limit posed by the rockshore platform the envelopes of change were of a smaller scale in comparison to the rest of the beach. The approximate net volume of sediment change over the beach from July to September was 11.37 m^3/m.

The shoreline profiles reveal alternating phases of vertical and lateral accretion, predominantly occurring on the nearshore and foreshore zones, as a result of seasonal wave height variability. The central portion of the beach is growing faster than its ends. This result is similar to the findings of Hanamgond and Chavadi (1992). The effect of seasonal wave height variability on shoreline profiles is also discussed by Frihy et al., (2004). Monitoring this vertical adjustment is important when trying to understand natural beach response processes. This is because beach height determines the level of protection from wave run-up. What this means is that as the wave height increases so does the size of the wave required to overtop the beach and erode the dunes (Cope et al., 1998).

Figure 6.11 shows the slumping of the dune front at the western end of the beach. This figure highlights the difference between the levels of dune scarp protection across the beach offered by gravel deposits and debris accumulations. The different levels of exposure and vulnerability to variable wave heights across the beach at Sandy Bay are also apparent. This means the dune system at the eastern end of the beach, closest to the cliffs, is only susceptible to change from higher storm waves as the wave height needs to be greater in order to exceed the gravel deposits and reach the base of the dunes. However, the beach base is also more readily lowered by smaller waves. The shoreline morphology at the western end of the beach is susceptible to change from lower intensity wave conditions due to a thinner barrier between the beach and dunes, therefore, the base of the dunes more readily modifiable. The active erosion of the sand dunes can be easily seen as in Figure 6.11.

Figure 6.11 Mass movement of the historical dune front at the western end of Sandy Bay. Note the lower level of protection to wave erosion offered by the thinner debris accumulation and gravel beach. Photograph taken early July 2009.

6.3.6 A finite sediment budget

The analysis of shore profiles and sediment depths along Sandy Bay suggests it is a restricted beach system with a finite sediment budget (Figure 6.12). This means that, due to the cliffs that back the beach, the amount of horizontal adjustment is restricted. The shallow depth of the sandstone bed beneath the sand deposits suggests that the beach's vertical adjustment is also restricted.

On the 28th July 2009 a series of holes were dug into the sediment along the length of Sandy Bay. This was done in order to gauge the depth of the consolidated sand bed. It appeared that the sediment of the bed was similar to the material in the cliffs adjacent to the river mouth. At the eastern end of the beach this bed lay at a depth approximately 0.15 to 0.61 m below the surface. The main material atop this layer was an unconsolidated coarse grained sand of the size range 0.13 mm or 2.94 phi. At the western end of Sandy Bay the consolidated sand bed remained at a depth of around 0.15 to 0.61 m. The type of sediment was coarser and the coarse-grained sand layer was much thinner, approximately 100 mm. This along-shore variation in depth of the coarse grained sand lense highlights the influence of the longshore transport of sediment along the promontory from west to east; hence we see a greater depth of finer sediment at the eastern end of the beach.

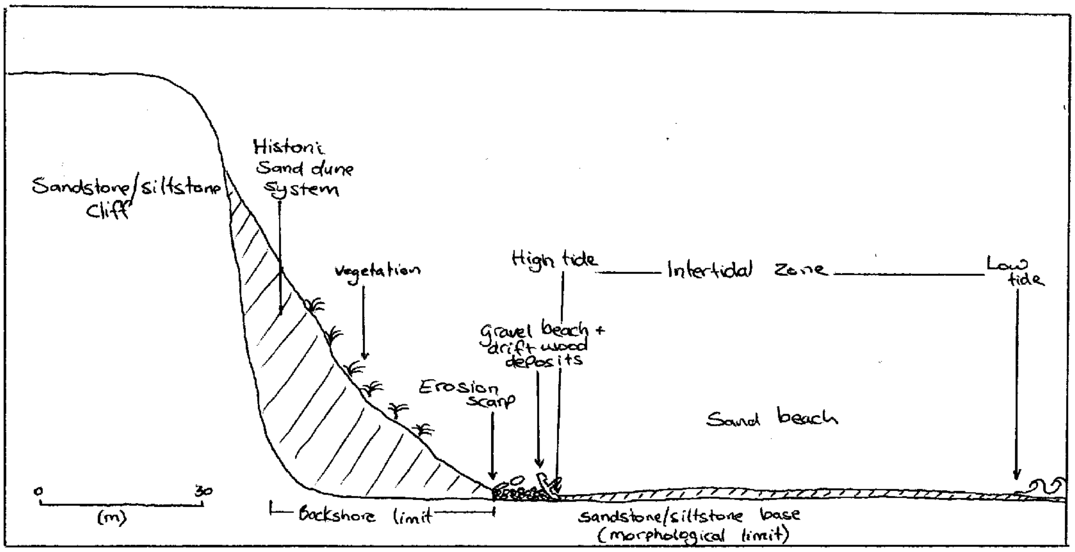


Figure 6.12 A cross section of the beach on Sandy Bay highlighting the morphological limits of the beach system. Derived from field observations throughout the three month field study period.

In Sandy Bay this littoral transport of sediment appears to operate in a net eastward direction along the promontory as the offshore littoral transport trends northwards. An across-beach profile indicates that there is a large zonal variation in sediment size (Figure 6.13) from coarse grained sands on the nearshore, mixed sands and gravels on the foreshore, to large unconsolidated pebbles, cobbles and driftwood on the backshore of the beach. These variations in sediment size indicate the ranges of wave energy the beach at Sandy Bay is exposed to, and the sorting that occurs during different tidal heights. According to Hanamgond and Havadi (1992) this form of sorting indicates normal sediment dispersion and swash and backwash processes are responsible for good sorting. The level of sediment sorting that occurs along the beach at Sandy Bay would indicate that there are cyclic phases of erosion and accretion in relation to different water and wave heights.

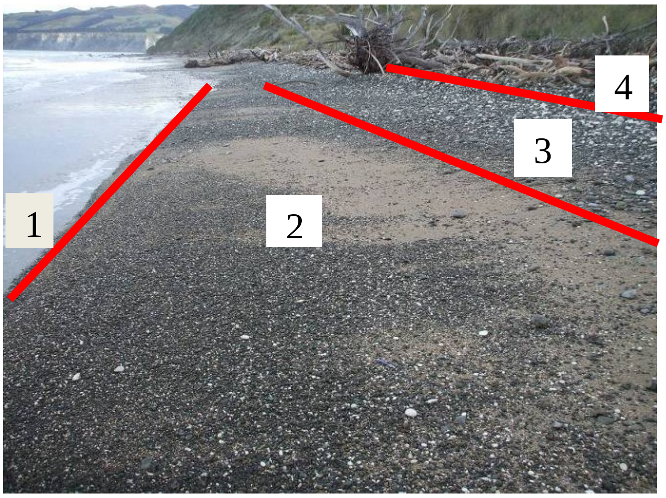


Figure 6.13 The range of sediment sizes on the upper beach section. Note the absence of fine sands on the upper beach (2, 3, and 4) but the clear line where the fine material and the horizontal beach surface begin. This level of sorting is related to the higher wave energy at the time the photograph was taken. Photograph taken 26th July 2009.

During high wave energy events the coarse sands are removed from the beach slope, resulting in the dominance of a composite beach form. Sands are then returned when weave energy is less turbulent. According to McGloin (2009) composite beaches are characterised by a sandy intertidal zone that is backed by a gravel berm. The coarser gravels mean the beach slope at Sandy Bay takes a steeper profile under such conditions than during periods where wave energy is lesser. This removal and then replenishment of the coarse sand material confirms a supply of sediment offshore, hence the seasonal variations in the coarseness of material on the beach.

6.3.7 Gravel beach deposit

The gravel beach and driftwood deposit have both positive and negative feedbacks on the beach system. From initial observations at Motunau, the gravel was seen as a reflective barrier blocking wave energy from eroding the sand dunes at the back of the beach. However, Brunel and Sabatier (2009) discuss the way in which the break in slope represented by a gravel beach can lead to a reduction in beach width. This is because the horizontal movement of the beach is restricted, which means the sediment supply to the beach is cut off. The profile analysis in Chapter Five supports the idea that the gravel beach deposit acts as a stable point on the beach, restricting the horizontal adjustment of the beach. As discussed in Chapter Two this has both positive and negative implications for beach nourishment in that it can reflect wave energy away from the sand dune base. This reflection of wave energy restricts the supply of sediment to the beach face. The continued narrowing of this pocket beach will result in the inevitable loss of the beach. This highlights another potential link between not only the starved nearshore sediment deposits but also a restricted terrestrial supply to the beach. As the headland cliffs continue to retreat and the eastern end of Sandy Bay is more exposed, the small pocket beach system will become progressively less self-regulating in terms of sand supply. This will result in the transfer of stored sands downdrift. A similar process was also outlined by Dehouck et al. (2009).

6.3.8 Seasonal variability

During the winter months, July to September, it appears we can expect to see a general net loss of beach sediments with smaller phases of accretion due to the greater wave heights. This is due to the dominance of the southerly storm surges during this study period. Southerly waves occurred 30.96 % of the time, as outlined in Chapter Five. A similar occurrence of southerly swell was also noted by Cope et al., (1998) for Pegasus Bay. Despite the southerly swell being the most frequently occurring, the larger waves appear to approach the promontory from an easterly direction as indicated in Chapter Five. This is because southerly waves are refracted around Banks Peninsula prior to arriving offshore of Motunau. Easterly waves, on the other hand, arrive from the Pacific over a greater fetch area and are less affected by the nearshore contours of the coastline.

6.3.9 Motunau shoreline orientation

Given the orientation of the Motunau promontory it seems plausible that the process of littoral drift is complicated and less efficient as a result of the turbulent nearshore wave environment. Motunau Island presents a block in the path of the net northern transport direction. As a result, sediment bypassing of the nearshore zone could be occurring as sediment naturally adjusts in order to get around the Motunau promontory. The presence of the sediment-bare rockshore platforms suggests that at certain times of the year, when the wave climate is turbulent enough, this bypassing of sediment is occurring (Figure 6.14). Such a process of sediment bypassing is discussed by Storlazzi and Field (2000).

Figure 6.14 The rockshore platform at the base of the eroding cliffs. Note the absence of fine sediments. Photograph taken looking west towards Sandy Bay 22nd August 09.

Sediment cannot enter the turbulent nearshore zone, therefore it must pass the nearshore in the deeper offshore waters. However, the protruding rock platforms can also reduce the amount of sediment loss offshore during storms (Brunel and Sabatier, 2009), as discussed in Chapter Two. The aerial photographs also reveal the likely occurrence of a major sediment gyre which may act to inject this sediment offshore into deeper water. This offshore transport of nearshore sediment has the ability to keep sand at depths that are beyond wave base reworking. Such a process can ultimately limit the amount of sediment available to the shoreline (Anthony, 2002). This offshore passage is likely linked to storm or high-energy wave events as this is when we expect to see the most drastic scouring of coarse sand sediment from the beach. As wave height increases sediment volume should decrease (Dubois, 1988). This process of offshore sand bypassing would suggest that the sediments already on the beach at Sandy Bay are being reworked by wave and tides between a possible nearshore bar deposit and the shoreline. The shoreline profiles in Chapter Five do reveal that this sediment is being removed from the beach during higher wave conditions, only to be returned during calmer swell conditions. When wave energy is higher it appears that this results in a net removal of sediment from the nearshore sediment budget. This has longer-term impacts on shoreline morphology.

6.3.10 Section Summary

- The last 6,500 years has been characterised by both transgressive and regressive phases of sea level. The current sea level is rising at a rate of approximately 1.8 mm yr^{-1}.
- Motunau experiences a combination of local and non-local wave conditions. There is a dominance of the northerly and southerly components. However, southerly waves are less modified by the bathymetric contours.
- Analysis suggests there is a decreasing amount of sandy sedimentation around the nearshore and shoreline at Motunau.
    - It is possible these sediments are being moved offshore to deeper water. This is resulting in the coarsening of nearshore sediments.
    - The existence of a turbulent nearshore zone at Motunau suggests that sediment bypassing may be occurring**.**
- The continual erosion and retreat of the shoreline is changing the shoreline orientation and, therefore, tidal and nearshore current patterns around the promontory.
- Localised circulations of water or eddies have likely favoured the deposition of sands historically. However, wave action has dissipated these eddies.
- Coastal subcells likely exist today along the length of the promontory, and are characterised by individual cycles of erosion, deposition, and transport. The two most readily observable cells are the Sandy Bay subcell, and the river mouth subcell. Exchange of sediments between these subcells appears only to occur when wave energy is higher.
- Offshore wave heights are linked to nearshore wave heights. Shoreline change is the result of a magnitude/frequency relationship.
- A lack of detailed bathymetric information limits further analysis of these subsystems.

6.4 Has the stabilising of the river mouth affected the supply of sediment to the base of the cliff and Sandy Bay inducing erosion?

From field observations it would appear that the lower reaches of the Motunau River have been characterised by change throughout the current interglacial period. There is evidence for the dynamic nature of the lower reaches of the Motunau River preserved in the current river bank. The river has been through phases of increased incision as the promontory has been uplifted at rates of 1.5 to 1.7 mm yr^{-1} (R.W. Morris and Associates, 1987), and as sea levels have risen and fallen (Figure 6.15). As the river has naturally adjusted to flow regimes and sea levels throughout the current post-glacial era, a sequence of paleo river beds have been produced and the river has avulsed to its current position which faces south-southwest.

Figure 6.15 Paleo-stream beds in the lower reaches of the Motunau River. Note the consolidated siltstones beneath the gravels associated with river deposits. The red lines indicate the unconformity associated with river channel incision. These indicate old river flow paths prior to it current position. Photographs taken July 2009.

A feature that may exist in the nearshore zone at Motunau is a bathymetric low associated with a paleo-stream channel incised during periods of lower sea level. This is a process also outlined by Storlazzi and Field (2000). In Chapter Two, Herzer and Lewis (1979) indicated this could be occurring at Motunau due to the presence of the buried Motunau Canyon. If such a feature does exist it could potentially act as a major sink of littoral sediments and, at the same time, interact with littoral currents to inject nearshore sediments further offshore. This could explain the large sediment plumes seen in the photographs in Chapter Two. Unfortunately there is insufficient bathymetric information available at this time to elaborate on such bathymetric features in the nearshore.

6.4.1 Channel form dynamics

From observations it appears that the river mouth at Motunau Beach exhibits a dynamic combination of both sand and gravel substrates. The greatest sediment transport capacity appears to occur during high velocity river discharge events. This is represented by the drastic drop in the base levels of the profile. The river flow during these high-velocity river events is further modified by channel constrictions as the channel adjusts to accommodate variable flow rates.

The presence of in-channel debris, such as wood or small debris falls, alters and obstructs the path of flow. These variables make for altering sequences of scour and fill. The dynamic nature of the sediments deposited in the river mouth mean that during times of low river flow events there are periodic variations in the depth of the channel along the length of the flow path (Wilkinson et al., 2008).

During high-energy river flow events it appears that the slope and area of the Motunau River channel increase, the general grain size becomes coarser, and the increase in channel roughness means that the flow becomes more turbulent. As fines are washed away, coarsening of sediments occurs, and the channel is less responsive to change as the coarser sediments are less easily removed from the channel bed. This process appears to have occurred in August 2008 and is one explanation for the low level of adjustments recorded in this 2009 study period. The hydraulics of the river becomes more influenced by the coarser grains. This ultimately means that to accommodate for the increased volume of water, channel form adjusts to find the most efficient route out to sea (Wilkinson et al., 2008). It is possible that these sporadic large-scale river flows in the Motunau River are the cause of the changing bed positions over the current post-glacial period, as depicted in Figure 6.15.

The type and quantity of sediment within the Motunau River channel is dependent on the channel form. The river mouth is approximately 100 m in width; whereas, the width at the mid channel section is constricted to approximately 50 m. At the first bend in the river, where the jetty is located, this area of channel expands to approximately 100 m in width. From observations it would seem that the narrower sections of the channel are more favoured towards the transport of sediment during the rising and falling tide phases. This is because the flow velocity is restricted, increasing flow velocity, and therefore has more influence on the bed form to suspend sediment and transport it. The areas of the river mouth that have larger widths are energy dissipative environments which favour the deposition of fine sands and silts (Figure 6.16).

One process that seems to be occurring during normal river flow conditions is the transfer of coarse sands between these larger area sections of the river mouth. The rising tide deposits material in the river mouth it is then transported upstream through the narrower channel sections. At slack tide fine sands and silts are deposited in the upper section. As the tide retreats sediments are moved seaward once again. They are then are deposited at the mouth due to breaking waves. The highly dissipative surf zone at the mouth of the river causes sediment-laden river water to be trapped by the waves along the shoreline, processes described for elsewhere by Wright et al. (1980) and Hicks and Hume (1996) in Chapter Two. Under normal river flow conditions this has implications for the distribution of sediment to surrounding areas in that it suppresses the amount of sediment dispersal to surrounding coastal cells. This results in a net gain of sediment at the mouth of the Motunau River. The ECan H2554 profile, situated at the mouth of the Motunau River, record supports the occurrence of these mechanisms as shown by phases of deposition during calm sea conditions, however, rapid scouring during large river flood events. Over the three month study period this profile showed the least amount of sediment adjustment of all five profiles with an estimated net volume change of 7.09 m^3/m.

Figure 6.16 View looking SW towards the Motunau River mouth. Note the variable widths across the length of the lower reaches. Photograph taken 2008.

6.4.2 Human modification

From the analysis of the wave patterns around Motunau, along with the regular shoreline profiles, it appears that the anthropogenic manipulation of the river mouth has had little or no effect on the sediment levels of Sandy Bay or the level of cliff retreat over the last 50 years. Structural interventions have provided temporary solutions for more effective human use of the area. In the longer-term it appears these have proved inadequate to curb any natural long-term coastal trends associated with sea level rise or local tectonics. The run down nature of the river channel guides suggests they have little effect on the distribution of sediment from the river to the likes of Sandy Bay. Wave energy crashes over the guides and through them as clearly depicted in Figure 6.17.

Figure 6.17 Inundation of the channel guides at the mouth of the Motunau River during high tide. Late June 2009.

Figure 6.18 Deposition and formation of a swash bar in the channel of the Motunau River is evidence the channel guides are doing little in way of distribution of sediment out of the channel. This swash bar confirms the wave dominance at the river mouth (18th June 2009).

In early July deposition of a swash bar formation began to occur in the mouth of the river. This had obvious implications for the safety of fishing vessels and the access to and from the river (Figure 6.18). It appeared this deposition occurred due to the erosion of the river bank on the seaward side of the river mouth, allowing wave energy to penetrate during high tides and deposit material (Figure 6.19). In response to this problem the swash bar deposit was excavated from the river channel and used to reinforce the bank (Figure 6.20). This however proved to be a temporary solution as the bank continued to erode and material was re-deposited back into the river mouth.

Figure 6.19 Erosion of the seaward river bank. a) A gap emerged in the bank between the sea and the river channel. b) Location of the breach on the seaward side of river mouth. 18th June 2009.

Figure 6.20 Excavated material from the river channel used to reinforce the bank. 13th July 2009.

This highlights the short-term nature of the link between human interventions and coastal processes along the promontory. In comparison to the longer-term processes of coastal change human interference in the river mouth area appears to have done very little.

It appears that the direction of sediment distributions have not changed as a result of the attempted stabilising of the river mouth. The water from the river mouth does not appear to be immediately affected by the northerly longshore transport due to the river mouth's orientation. It is possible that beyond the 10 m depth contour this is occurring. Evidence for this northern trending of the river mouth is indicated by the subsidence of the channel guides on the seaward side of the channel and the profile form during floods.

There is a net northward sediment movement along the nearshore which is combined with smaller-scale temporal changes. For example, during large river flood events the velocity of river water expelled from the mouth would be sufficient to deposit material into the nearshore zone which is then reworked onto the beach at Sandy Bay. Evidence for this is the bands of driftwood. During normal conditions one can expect very little interaction between the river mouth and Sandy Bay. Under storm wave conditions it is possible that material can be transferred to the river mouth from Sandy Bay. This exchange between the coastal subcells was discusses previously in the chapter. Shoreline profiles suggest river flows were not substantial enough to permit any large-scale change to the form of the river channel over the study period July to September 2009.

6.4.3 Section Summary

- The lower reaches of the Motunau River have been characterised by change over the past. This is from both tectonic and sea level influences.
- The natural hydraulic adjustment of the river has been preserved in the river bank and also by the presence of the paleo-stream bed in the sand dunes on the true-left of the river. Furthermore, Herzer and Lewis (1979) indicate the possibility of bathymetric lows within the nearshore associated with historical feeder channels.
- High river discharge events are crucial for initiating natural river adjustment.
- Structural interventions have proved temporary and have had little or no effect on the long-term coastal change around the Motunau promontory.

6.5 What are the management implications for the area over the next 10 years?

Despite the temporal and spatial fluctuations in beach level at Sandy Bay the longer-term trends in the morphology of the shoreline suggest there is a net loss of material from the shoreline. The longer-term beach morphology is the result of high-intensity low-frequency conditions, whereas surface characteristics are related to low intensity high-frequency events (Jackson et al., 2002). The effects on the shoreline of these low-frequency conditions should be expected to increase with sea level rise and an increase in the wave height around the promontory.

As shoreline erosion continues there will be an ongoing threat to the width of the beach at Sandy Bay and the protection provided to the sand dune system at the back of the beach. This will have further implications for the property development that is currently occurring along the top of Sandy Bay. It is also likely there will be an increasing volatility around the river mouth associated with the continued inundation of the river banks and channel guides. This can be expected to pose a threat to the navigation safety of the fishing vessels and the banks of the car park along the parade. Continued down wasting of the rock shore platform at the base of the cliffs will provide an effective mechanism by which wave action will continually remove debris that have accumulated at the foot of the cliff. This will result in the continued parallel retreat of the cliff line, posing a continued threat to the properties that exist along the cliff top. Structural solutions have proved ineffective in the past and will continue to do so in the future. The river guides do provide an effective mechanism for wave energy dissipation if maintained appropriately. It seems necessary to review the alignment of the guides in relation to the wave approach direction for a more effective management strategy in terms of boat safety and control of sediment volumes within the channel. As Motunau Beach continues to be a popular destination for fisheries access and holiday makers it would be appropriate that investigation into the coastal processes associated with the promontory continue.

6.5.1 Section Summary

- Analysis of the Motunau Beach coastal environment suggests there is a net loss of material from the nearshore and shoreline.
- Continual loss of cliff will result in the continued narrowing of Sandy Bay. This has implications for the integrity of the recreational asset.
- As sediment buffer is reduced the effects of the high-intensity and low-frequency wave events is likely to increase posing considerable risk to Sandy Bay, the cliff, and the river mouth. This increasing volatility surrounding the river mouth will pose further navigation safety issues in the future.
- Further investigation and continued coastal monitoring will be essential in order to expand current understandings of short term trends with the longer scale coastal change.

6.6 Chapter Summary

Loss of shoreline at Motunau appears to be prevalent on the beach at Sandy Bay which in turn has enhanced the rate of cliff collapse. There is also a continual degradation of the shoreline at the mouth of the Motunau River. The results of this investigation suggest that this erosion is due to an abrupt loss of fine sediment from the nearshore which was historically accountable for maintaining beach width and shoreline profiles. My analysis of shoreline observations imply that the position of Motunau Island and the orientation of the promontory suggest there is potential for offshore deposits of fine material beyond the island or in the nearshore zone; however, these have not yet been located and may provide valuable understandings in the sediment transport processes of Motunau. Throughout the three month study period it appeared that there was little interaction between the river mouth and sediment levels on Sandy Bay. From this I suggest during normal river flow conditions there is little exchange of material between the zones. The beach at Sandy Bay can bring sediment eastwards via longshore drift to the mouth of the river due high wave events.

Chapter Seven

Conclusions

7.1 Introduction

At Motunau Beach the combination of qualitative and quantitative research techniques have proved to be an effective alternative to the modelling of coastal evolution. This is due to the limited background information currently available on the coastal processes and the understandings of the morphodynamics at this site. It was important to expand on the existing knowledge base and highlight areas which need further expansion, such as the hydrographic information and sediment transport paths. This form of analysis can then pave the way for more specific modelling of the coastal processes, such as wave refraction and sediment transport around the promontory. The initial objectives of this study as outlined in Chapter One were as follows:

- To outline the processes causing cliff erosion at Motunau.
- Describe the role bathymetry of the nearshore zone has in initiating changes to the shoreline morphology.
- Describe the relationship between the lowering of the rock platform and the links between the retreating cliff and loss of beach width on Sandy Bay.
- Outline in detail the possible effects the stabilising of the river mouth has had on the supply of sediment to the base of the cliff and Sandy Bay.
- From the analysis of results outline the management implications for the area in the next 10 years.

7.2 Chapter summaries

Chapter One introduced the research questions that were conceived in order to guide this research. This chapter highlighted the gap in the knowledge around the coastal processes at Motunau and also introduced the key coastal processes that were going to be analysed throughout this 2009 study. Chapter One also outlined the aims and methods that were to be used throughout this research.

Chapter Two discussed the key coastal processes that were occurring at Motunau Beach within a broader New Zealand and International context. In doing so it provided background understandings to the processes that were occurring and highlighted potential links between the processes. This chapter also highlighted that there is a complex of coastal processes interacting at Motunau and distinguished the Motunau circumstances from examples in the literature.

Chapter Three provided an analysis of the geological background, ultimately determining the way the coastal processes function and the effects wave energy can have on shoreline morphology.

Chapter Four introduced an in-depth analysis of the Motunau wave climate since 1979 to the current 2009 study period. This data was based on NCEP wind input data and was used in the formulation of modelled wave data. This analysis was used to look at trends in the wave climate since 1979 and put the data from the 2009 study period within context.

Chapter Five outlined the results derived from the July to September 2009 field study period. The shoreline profiles along with the observations were a few of the techniques outlined in the methodology in Chapter One.

Chapter Six provided a synthesised discussion of the results outlined in previous chapters. This chapter aimed to interpret and explain trends that were observed during the study period. This chapter was used to link qualitative observations and quantitative research techniques and put these within a broader context of coastal change.

Chapter seven provides a breakdown of the thesis, summarising the main findings of the research along with its limitations and gives recommendations for future research.

7.3 Summary of main findings

7.3.1 Outline the processes causing cliff erosion at Motunau

The results of this investigation suggest that there has been a net depletion of sediment from the nearshore environment at Motunau Beach. This has resulted in the loss of beach width on Sandy Bay and consequently a loss of sand dunes. The exact reasons for this sudden loss are not clear. However, my analysis of the wave climate since 1979 indicates that an increasing wave height is changing the shoreline orientation and therefore sedimentation patterns around the Motunau promontory. The drastic loss of beach width, by approximately 25 m between 1950 and 1968, resulted in a lag phase between the loss of beach and then the loss of cliff in the late 1970s and early 1980s. The removal of beach sediment narrowed the buffer that existed between the wave energy and the cliff foot. Once this had occurred, waves refracted into Sandy Bay were able to produce a redistribution of wave energy to form concentrated pockets of erosion along the shoreline. My analysis and field observations indicate that this is occurring at the eastern end of Sandy Bay. Subaerial weathering, in combination with wave attack, is resulting in the parallel retreat of the cliffs at Motunau Beach.

7.3.2 Describe the role bathymetry of the nearshore zone has in initiating changes to the shoreline morphology.

My analysis of the Motunau Wave climate, seaward of the 10 m depth contour, indicates that the wave environment here is similar to the rest of the east coast of South Island. Prevailing wave directions occur from a southerly and northerly direction. Results from the wave refraction analysis in Chapter Five suggest that southerly waves are less modified by bathymetric contours compared to the north-easterly waves. The processes of wave refraction, along with wave shoaling over the nearshore zone of varying depths, redistributes and transforms the wave energy. This results in across-shore variations in concentrations of wave energy. Shoreline responses to this wave energy vary spatially, as indicated by the shoreline profile analysis in Chapter Five.

Profile analysis revealed differing rates of erosion and sand accumulation along the shoreline at Motunau Beach. This potentially favours the existence of subcells within Motunau coastal zone as a result of bathymetric controls on wave form and shoreline orientation. From my observations this would explain the variable zones of sediment erosion and accretion at the shoreline. From the analysis of field results, beach response trends are a direct result of offshore wave heights. Results from the wave climate analysis and shoreline profiles indicate a magnitude-frequency relationship exists between the occurrence of wave heights and sediment levels on the beach. That is, high-intensity and low-duration wave height events have less of an effect on sediment levels along the beach in comparison to high-magnitude events of longer duration.

7.3.3 Describe the relationship between the lowering of the rock platform and the links between the retreating cliff and loss of beach width on Sandy Bay.

The soft nature of the consolidated bed beneath the rock shore platform means that it is subject to high rates of basal lowering as wave action leads to abrasion. This lowers the shore platform, meaning that wave energy has a greater influence on the foot of the cliff. As the headland cliff retreats it exposes the eastern end of Sandy Bay to an increasing level of wave action and sediment redistribution. This leads to levels of sediment depletion at the eastern end of the beach, as highlighted by the shoreline profiles in Chapter Five. This also means that the consolidated sandstone bed beneath the beach is more readily subjected to lowering via wave action, as was observed throughout the study period. In turn, my results indicate that the beach level is lowered, making the eastern end of the beach more susceptible to modification from lower wave heights.

7.3.4 Outline in detail the possible effects the stabilising of the river mouth has had on the supply of sediment to the base of the cliff and Sandy Bay.

From my field observations it appears that the Motunau River has been characterised by natural hydraulic adjustment and avulsion throughout the current interglacial period. The lower reaches of the river have adjusted to variable flow regimes and adjusting sea levels. Observations and profiles suggest that attempts to stabilise the river mouth, by rock walls, has altered the rivers natural adjustment, resulting in the down cutting of the river bed rather than the lateral dispersal. This can be seen by the subsiding rock wall on the seaward side of the river mouth. Results of this investigation indicate that down cutting makes it is harder for the river to avulse under normal flow conditions, however during floods this can still occur. This process was discussed in Chapter Five. The stabilising of the lower reaches of the river channel has had little effect on the sediment supply to the cliff base and sediment levels on Sandy Bay. Results of this investigation indicate that the river mouth, the cliffs, and Sandy Bay act as separate subsystems having little influence on each other during normal or non-storm sea conditions.

7.3.5 From the analysis of results outline the management implications for the area in the next 10 years.

The results of my study suggest that over the longer-term, the effects of human modification have had little or no observable impact on the shoreline orientation. The larger trends of change and shoreline loss are attributed to regional scale processes, such as sea level rise and local tectonics. On the shorter timescales, these impacts of human interference are more readily seen, such as the redistribution of sediment from the river mouth to favour human use. Over the next 10 years there will be continued loss of cliff line, with this come associated problems with hazard mitigation in regard to the housing along these cliffs. This continued cliff retreat will favour the remobilisation and redistribution of sediment from the eastern end of the Sandy Bay, resulting in a continual loss of beach width across Sandy Bay. In addition, the hazard zones will have to be reassessed having possible implications for the subdivision occurring along the top of Sandy Bay. The river mouth will continue to degrade and be less stable as a result of wave heights continuing to increase as sea level continues to rise. This will pose considerable risk to the safety of local fisheries, no doubt prompting more piecemeal attempts to curve the problem of shoreline change. A more substantial effort needs to be made, for example an effective management strategy from the likes of the local Hurunui District Council, The Department of Conservation, and Environment Canterbury, along local residents. Over the past structural solutions have proved ineffective and temporary and will continue to do so in the future.

7.4 Summary of key conclusions to take from this research

- Sandy Bay experienced a sudden loss of beach width by approximately 25 m between 1950 and 1968. This was then followed by an enhanced rate of cliff collapse in the 1980s.
- My results indicate that historical nearshore sediment supplies are being depleted and transferred offshore during large wave events, where they are not being returned towards the shoreline during calmer swell conditions.
- As a result of this loss of shoreline buffer the Motunau coastal orientation has been exposed to a periodic increase in the rate of change.
- An increasing permanent settlement on the Motunau promontory has resulted in shoreline change events being more noticed and better documented.
- Results indicate that average significant wave heights are increasing.

- A magnitude frequency relationship exists between the wave heights seaward of the 10 m bathymetric contour and sediment levels on the beach. Shorter-duration and high-magnitude events are more likely affected by the shallower contours therefore wave energy has less an effect. Prolonged high-intensity events expose the shoreline to greater wave energy over time.
- Southerly waves are less affected by the bathymetric contours therefore more deep water wave energy is received at the shoreline in comparison to the north-easterly waves where wave energy is refracted and dissipated prior to reaching the shoreline.
- The Motunau promontory can be divided up in to a series of coastal subsystems; the river mouth subsystem, the cliff subsystem, and the Sandy Bay subsystem. My results indicate that the Sandy Bay subsystem can be further divided into a series of subcells due to the different wave energy exposures along the length of the beach.

7.5 Limitations of research

Due to the combination of user and instrument error a few survey periods had to be inferred due to incorrect data. This was indicated previously in Chapter Five. This potentially could result in a level of statistical error associated with analysis of profile volumes. Furthermore, the sediment volumes and rates of change are in relation to the baseline survey on the 30th of June. Questions are raised to whether this volume is a realistically representative baseline, or whether it is simply a snap shot in time. As such, the quantities of sediment change should only be taken as estimates of gross changes over the study period.

The wave data supplied by NIWA was based on wind inputs; therefore, the data is synthetic (modelled) rather than actual wave data. The use of these data sets gives continuous wave data with few gaps; however, to get the most from this information, it should be used in combination with observations (Appendix B). These techniques may introduce a level of error based on the wave model accuracy, although the use of such hindcast data is standard in coastal research today.

The study period conducted over the three months July to September was focused around gathering and observing high-frequency shoreline trends; therefore, this period could be said to be unrepresentative of beach processes over a full season or year.

The aerial photograph analysis of the Sandy Bay shoreline and cliff line was carried out using GIS techniques. There is potentially a level of error associated with the orthorectification of images. Furthermore, the most recently available aerial photograph was taken in 2004 and so is not representative of the current shoreline morphology in 2009. Large-scale shoreline change occurred in 2008 and has not been included in this analysis due to a lack of data. An up to date orthorectified aerial photograph of the promontory should be a priority in future research of Motunau so that the analysis of shoreline trends can be taken further.

This type of descriptive analysis of the Motunau promontory could also be open to criticism due to the high level of subjective observations. This has resulted in a large amount of theorising about the possible coastal processes and their interactions. Every effort has been made to base this theorising on up to date literature and detailed field observations.

The wave refraction analysis is a technique that gives very broad-scale observations of the wave climate and the propagation of deep water waves in shallower coastal waters and should be interpreted as such.

7.6 Suggestions for further research

A detailed study of the nearshore bathymetry needs to occur in order to better understand possible features in the nearshore. In future research this needs to take priority. It was initially hoped that this would be done in early July 2009; however, due to financial limitations it was not conducted. A study of the nearshore bathymetry would potentially indicate sediment transport pathways around the Motunau promontory and possible sediment sinks. An analysis of the nearshore bathymetry could also provide information on the form of the river mouth deposit.

Longer-term shoreline profiling across the length of Sandy Bay would give a better scope of change, indicating trends of beach adjustment over a longer time period. These profiles have not been done on Sandy Bay in the past. However as proven by my 2009 study, the ECan H2458 cannot be deemed representative of the entire beach system. These profiles therefore need to be continued in the future.

In early July 2009 a Digital Elevation Model (DEM) of the rock shore platform at the base of the eroding cliffs was conducted. It was hoped this would provide a good visual tool for elevations at the mouth of the river, and that this survey would depict the river mouth bar, thus providing information about its morphology. However it was not used in the body of the thesis due to the limited clarity of the results and lack of previous data on which to compare it with. This DEM would have been of more use if it was extended to include the beach at Sandy Bay along with the cliff line above the shore platform. Due to health and safety procedures, the cliff line could not be surveyed. Furthermore, the survey was conducted within an area where shoreline profiles have not been conducted making overlay inapplicable. In conjunction with the DEM survey, LIDAR data was obtained from ECan. However, at the time this LIDAR data was flown in 2004, it was high tide. The beach and shore platform was covered by water and was not recorded. Therefore, the DEM and LIDAR datasets could not be compared. The LIDAR data was very detailed, but since it was a one-off snapshot there was limited data to compare it with. Shoreline profiles could not be accurately added to the data set. Therefore use of this data set was beyond the scope of the present study but could form the basis of a future study focusing on the subaerial part of the field area.

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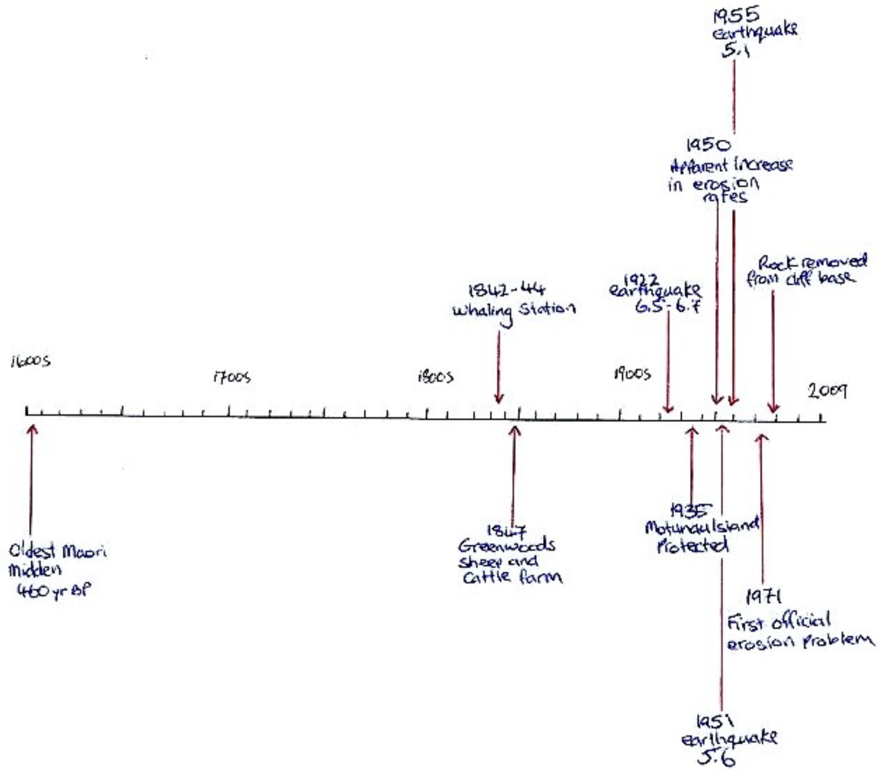
Appendix

Appendix A: Timeline of events at Motunau Beach



Appendix B: Field observations over the three month study period July to September 2009

Date:	Observations:
Monday 29th June	Weather was overcast and drizzly. Dominant wave direction appeared to be from N/NE. Wave conditions were choppy around the river mouth and out around the island. Wave height was approx 2ft (0.6 m) around low tide in the afternoon. Witnesses commercial vessels coming back into the mouth of the river. Low tide was at 4.10pm (-0.83).
Tuesday 30th June	N/NE wave direction. Net transport direction appeared to be heading south due to wave angle. Very mixed wave conditions in the nearshore. Wave crests approx 30° to Sandy Bay shoreline. Approx 8 sec wave intervals
13th July	Overcast but still. Sea conditions are relatively flat, not choppy. Gentle rolls approaching parallel to the shore. Approx 9 sec wave intervals. Waves are breaking around the island, however, appears to be very little effects of wave refraction and joining of wave trains. Waves are refracted and break at the cliff headland and at the mouth of the river. I'm guessing a dominant E wind direction due to angle of waves approach, perhaps a slight NE influence. Very pleasant but cool. Low tide was at 2.35pm
15th July	At 1.36pm wave lengths are very mixed in the nearshore with wave heights of approx 1 to 2 ft (0.3 to 0.6 m). Wave intervals approx 10 sec but there is a lot of variation. There is a cool onshore breeze, wave directions from NE/E/SE. Angle of wave approach also mixed but predominantly parallel to the shoreline at Sandy Bay. Beyond the island sea conditions are reasonably

	calm; i.e. no white caps.
Monday 27th July	At 1 pm sea was very calm low wave energy. Slight onshore wind but no white caps. There is refraction of the wave crests occurring around the base of the headland cliffs but wave trains approaching Sandy Bay very parallel from an E direction. Wave climate around river mouth very calm; heights approx 1 ft (0.3 m). Rock platforms at either end of Sandy Bay very exposed signs of significant scouring of Sandy Bay. Dug a series of holes along the length of Sandy Bay in order to gauge depth of clay bed; similar to the material exposed at cliff toe-possible link. Clay bed is very accessible within depth from surface around 1 ft (0.3 m) (different grain sizes along beach profile). At end of beach closest to eroding cliff gravel barrier and sand layer much thicker than other end. Is it material from the cliff?? Or indications of longshore drift direction?? Fishermen have attempted to clear channel and fix section of channel wall that was eroding it has clearly failed. Material dug-out and deposited on river bank has been eroded, no doubt back into the channel!!
Tuesday 28th July	Sea is very calm, no wind or whitecaps. Slight refraction of waves is occurring around the island however appears to be very little energy behind the wave trains. Waves dominantly from NE. Heights around the river mouth approx 1 to 2 ft (0.3 to 0.6 m). At the time these observations were recorded the tide was retreating. Angles of wave crests in the nearshore very variable.
9th August	Profile pegs at the western end of Sandy Bay have been buried under approx 15 cm of coarse sand and shelly gravel. Slight NE wind, turned stronger in

	afternoon. No white caps. Parallel angle of wave approach to Sandy Bay. Appears to be a large sediment plume in the nearshore zone heading SW. Wave breaking to the left (north) of the island. Wave heights approx 1 to 2 ft (0.3 to 0.6 m).
Saturday 22nd August	NE sea conditions. Light onshore breeze. Waves approx 3 ft (0.9 m) in height approaching parallel to the shoreline. Could not locate profile peg at western end of Sandy Bay due to large volume of deposited material.
Sunday 23rd August	Strong swash in nearshore on Sandy Bay was difficult to stand steady when surveying. Could feel the strong southerly longshore drift which is occurring during NE wave/wind conditions. Beach is very responsive to these changes in wind/wave energy; hence, we see the temporal and spatial variations in sediment depth along shore. Towards the cliff sand appears to be shallower and large areas of the clay base is exposed as recorded in ECam H2458. Possibly due to shadow effects by cliffs and rockshore platform. SB3 has deposited significantly, little erosion has occurred at the dune face by direct wave attack; however, evidence of subaerial weathering can be seen. Strong NE waves, white caps to north of the island. Approx 10 sec wave intervals; however, nearshore wave environment very complex.
Friday 4th September	No white caps in nearshore zone; however breakers at shoreline approx 3-6 ft (0.9 to 1.8 m) along Sandy Bay. Sandy Bay showing clear signs of deposition (buried pegs) and slope of beach as radically reduced. Wave intervals are approx 10 sec. Angle of wave approach is parallel to the shoreline at Sandy Bay, rolling in from beyond the island indicating E/NE conditions. The intensity of the onshore wind has increased across the day.

	Nearshore was very murky indicating high sediment content. At profile location SB1 there was approx 48 cm of material atop the clay base; 23 cm sand layer; 24 cm shingle layer. Swash appearing to be trending in an E direction along the beach with breaker heights approx 4 ft (1.2 m). Late afternoon temperature was very cold with a strong wind.
Saturday 5th September	Very calm sea conditions with no white caps. Slight breeze with approx 16 sec wave intervals. Wave heights approx 1 ft (0.3 m). Angle of wave approach in nearshore is parallel to the shoreline coming from E. Less of the clay base is exposed along the beach indicating deposition of sand.
16th September	Calm sea conditions with a slight onshore breeze. Breakers at the mouth of the river approx 1 ft (0.3 m).
17th September	Very calm sea conditions, only a slight breeze hard to tell dominant wind and wave directions. No white caps at all except in breaker zone approx 2 to 4 ft (0.6 to 1.2 m). Wave approach is parallel to the shoreline; appear to be refracted around the island and then into Sandy Bay. Approx 10 to 12 sec wave intervals but difficult to be accurate due to mixed crest intervals and angles. Sandy Bay exhibits mixed areas of deposition; all my pegs have been buried by an inconceivable amount of coarse sand except the ECan H2458 profile. This is interesting as there is supposed to be a net northward sediment transport however this would indicate otherwise. This sediment starving is potentially due to the eastern end of the bay being sheltered and less exposed to wave energy therefore sediment bypassing is occurring.

Tuesday 29th September	High tide approx 12.00 am. Wave run-up is only to the base of the gravel beach. Intervals of approx 10 sec. heights 3 to 4 ft (0.6 to 1.2 m) with a brisk onshore wind. Not cold. Waves appear to be refracting into Sandy Bay with a net southward movement indicating strong E/NE winds/waves. High tide did not reach the base of the debris slump at the foot of the cliffs
Wednesday 30th September	S waves with 3 to 5 ft (0.9 to 1.5 m) breakers. Strong S onshore wind. Wave lengths appear to be considerably shorter, with intervals of approx 5 to7 sec. Higher wave energy generates a greater turbulence in the nearshore zone due to breaking waves and whitecaps

Appendix C: Average wave heights, periods, and direction of approach. 15th June to the 30th September 2009.

Date:	Significant Wave Height (m)	Wave Peak Direction (deg from north)	Wave Peak Period (s)
15-June-09			
	2.09	175.80	8.10
30-June-09			
	1.87	284.34	7.72
15-July-09			
	1.41	129	7.83
27-July-09			
	1.07	182.54	7.00
9-August-09			
	1.64	238.88	7.30
22-August-09			
	1.35	239.17	7.87
4-September-09			
	1.46	217.13	7.15
30-September-09			

Appendix D: Coordinates for each of the shore profiles, the crack, and the debris slump

Description	Northing	Easting
Slump	5233770.346	1605811.173
Crack	5233684.200	1605978.555
Ecan H2554	5233678.693	1606243.692
SB3	5233813.202	1605356.813
	5233785.212	1605363.807
SB2	5233826.185	1605497.758
	5233782.202	1605501.752
SB1	5233824.174	1605634.704
	5233816.178	1605633.704
	5233771.195	1605636.698
Ecan H2548	5233827.161	1605782.646
	5233763.187	1605760.649

Projected Coordinate System NZGD 2000 New Zealand Transverse Mercator

Appendix E: RMS values for the aerial photograph comparisons 1950 to 2004.

Date of aerial photo:	**Number of GCP's:**	**R.M.S value (m):**
1950	4	3.03081
1968	4	2.46349
1976	4	3.10481
1980	4	0.34663
1993	4	1.99451
1995	4	0.00002
		Mean R.M.S=1.82337
Length of 2004 pixel=2.93666 m		

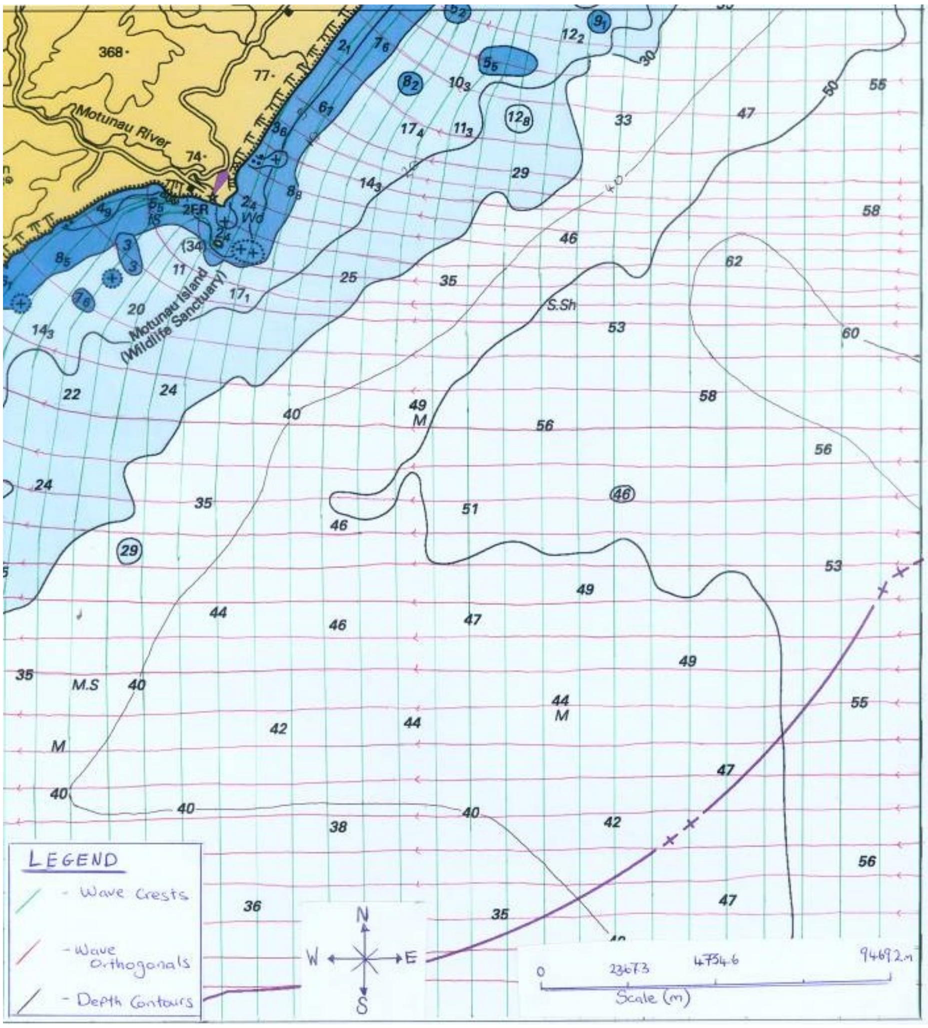
Appendix F: Profile volumes and changes between field visits 30th June to the 30th September 2009. Negative values indicate erosion and positive values indicate accretion.

	30/6/09	15/7/09		27/7/09		9/8/09		22/8/09		4/9/09		17/9/09		30/9/09	
Profile:	Profile Vol (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)	Profile Vol (m^3/m)	Vol Change (m^3/m)
SB3	84.84	88.76	3.92	89.52	0.75	87.25	-2.27	87.3	0.05	89.3	2	88.26	-1.04	89.6	1.34
SB2	158.88	165.97	7.09	126.88	-39.09	153.60	26.72	171.75	18.15	174.38	2.63	168.08	-6.3	171.75	3.67
SB1	126.64	160.45	33.81	146.57	-13.88	176.19	29.62	171.72	-4.47	173.57	1.85	174.21	0.64	176.95	2.74
ECan H2458	57.61	52.22	-5.39	53.97	1.75	87.87	33.90	94.63	6.76	85.07	-9.56	76.64	-8.43	51.56	-25.08
ECan H2554	7.09	1.37	5.72	8.19	6.82	5.11	13.30	2.97	-2.14	1.57	-1.4	7.27	5.7	6.94	-0.33

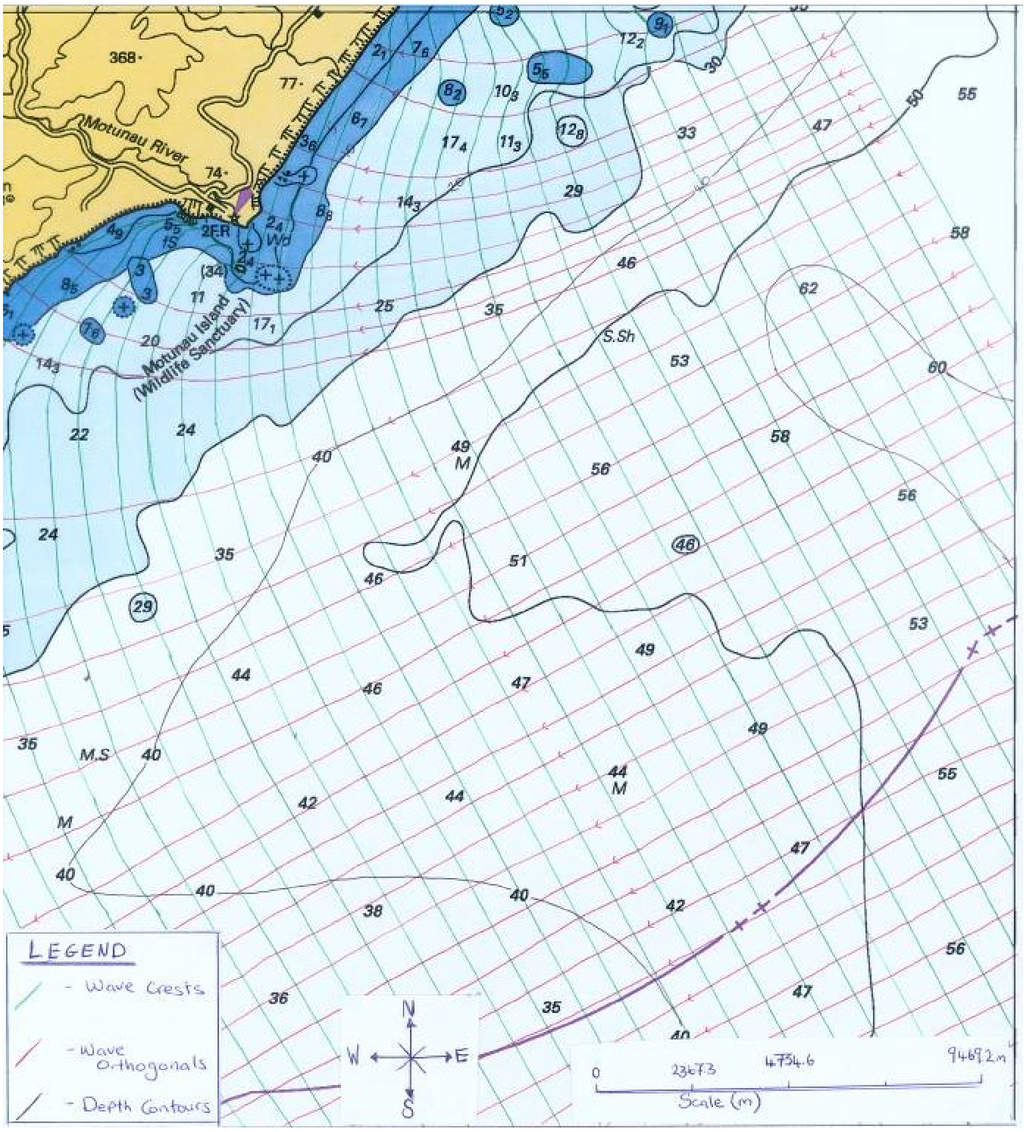
Appendix G: Total beach volume change along Sandy Bay 30th June to the 30th September 2009. Negative values indicate erosion of beach material and positive values indicate deposition.

Date:	30/6/09	15/7/09		9/8/09		22/8/09		4/9/09		17/9/09		30/9/09	
Profile:	Total Profile Vol (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)	Total Profile Vol (m3/m)	Total Vol Change (m3/m)
SB3	16280.80	17033.04	752.25	16743.28	-434.65	16752.87	9.59	17136.67	383.80	16937.09	-199.58	17194.24	257.15
SB2	27120.82	28331.08	1210.26	26219.52	4561.10	29317.73	3098.21	29766.67	448.94	28691.26	-1075.41	29317.73	626.47
SB1	16678.49	21131.27	4452.78	23204.22	3900.95	22615.52	-588.70	22859.17	243.65	22943.46	84.29	23304.32	360.86
ECan H2458	8549.32	7749.45	-799.88	13039.91	5030.76	14043.09	1003.18	12624.39	-1418.70	11373.38	-1251.01	7651.50	-3721.87
Total Volume (m3/m)	68629.42	74244.84	5615.41	79206.93	13058.16	82729.21	3522.18	82386.89	-342.32	79945.18	-2441.71	77467.78	-2477.40

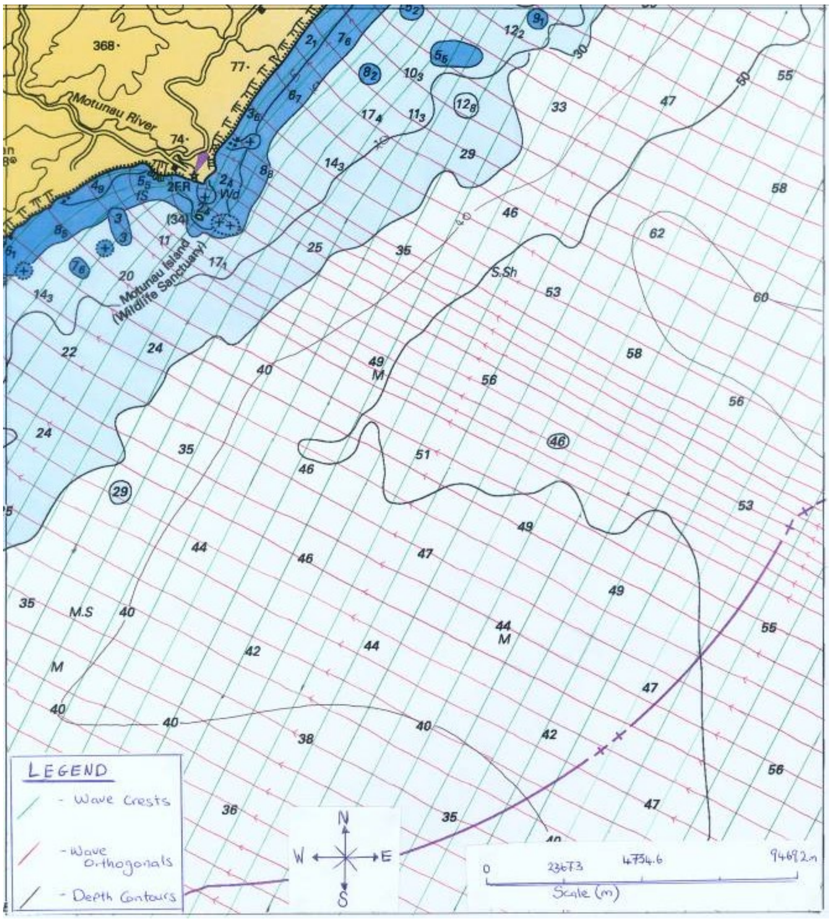
Appendix H: Refraction maps for each of the prevailing wave directions at Motunau Beach



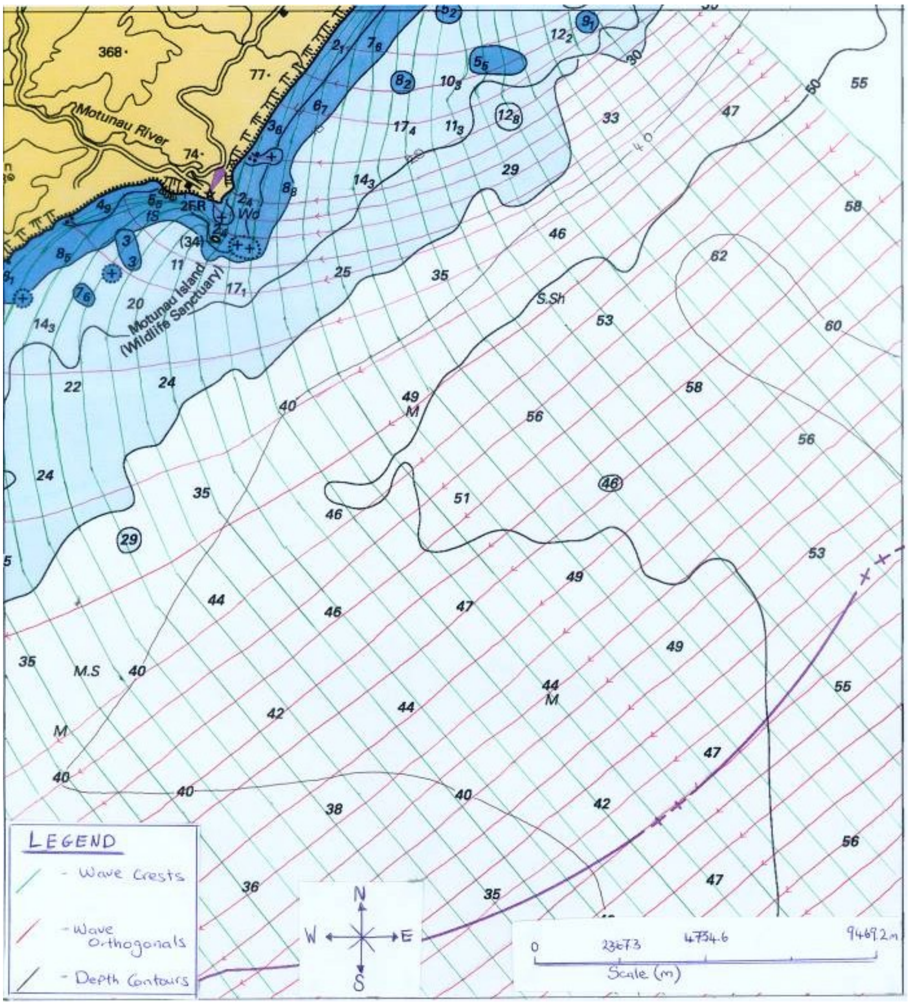
wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the east



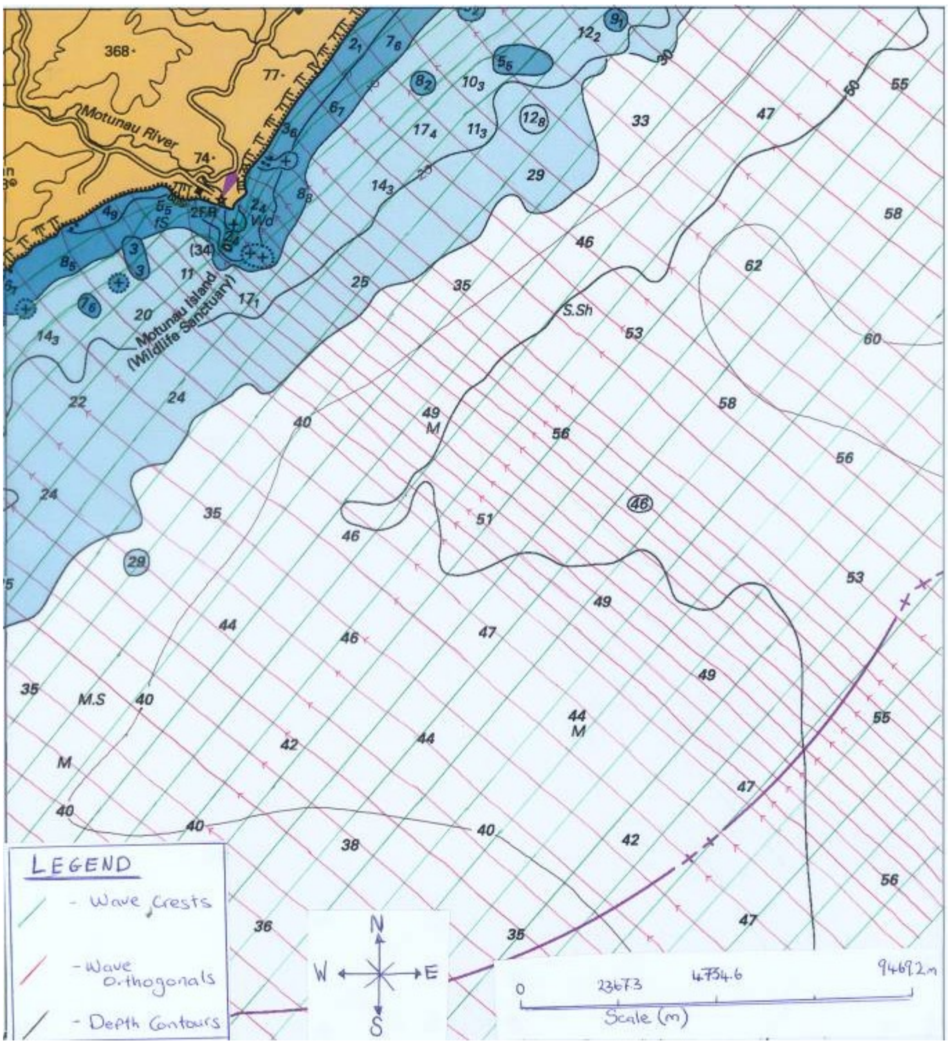
wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the east-northeast



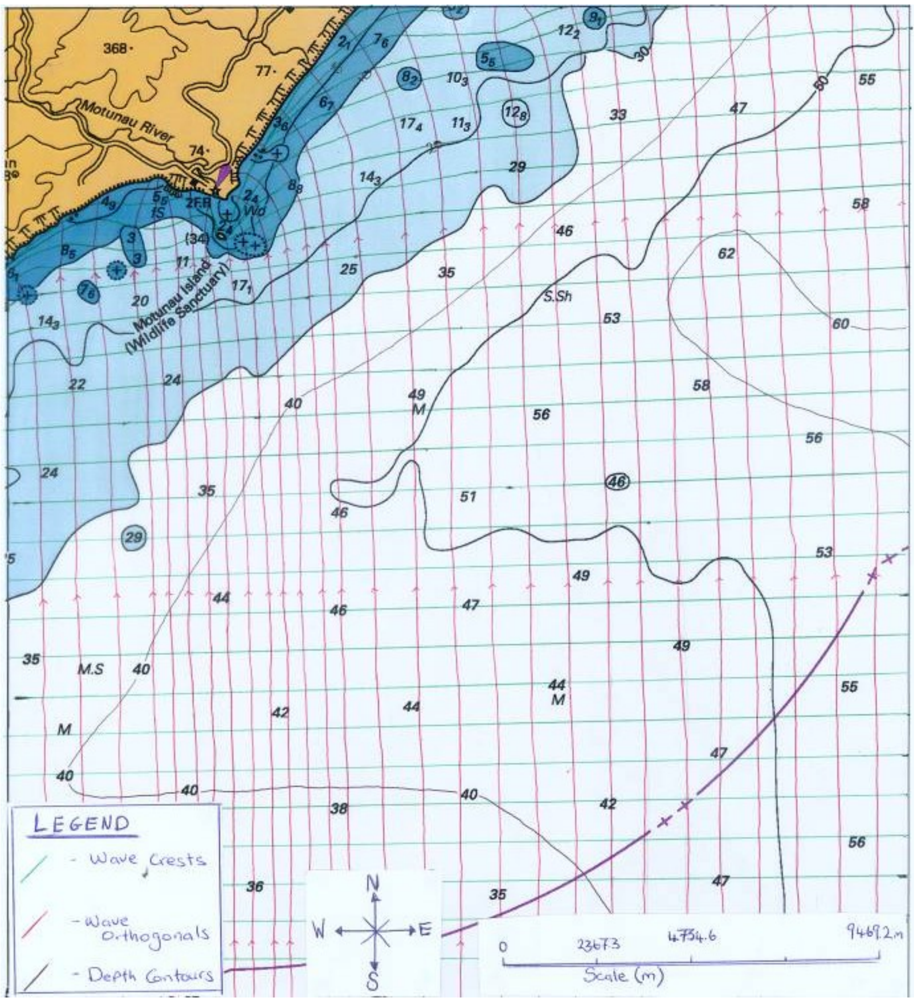
wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the east-southeast



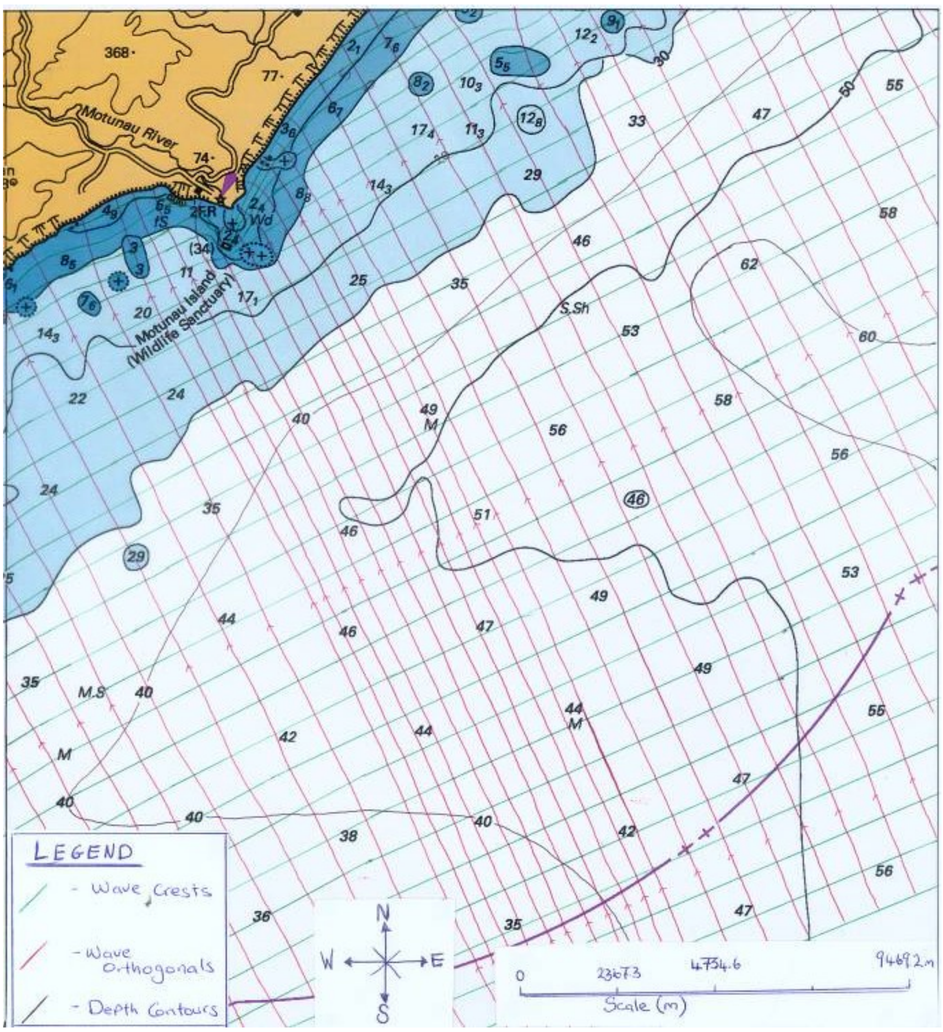
wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the northeast



wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the southeast

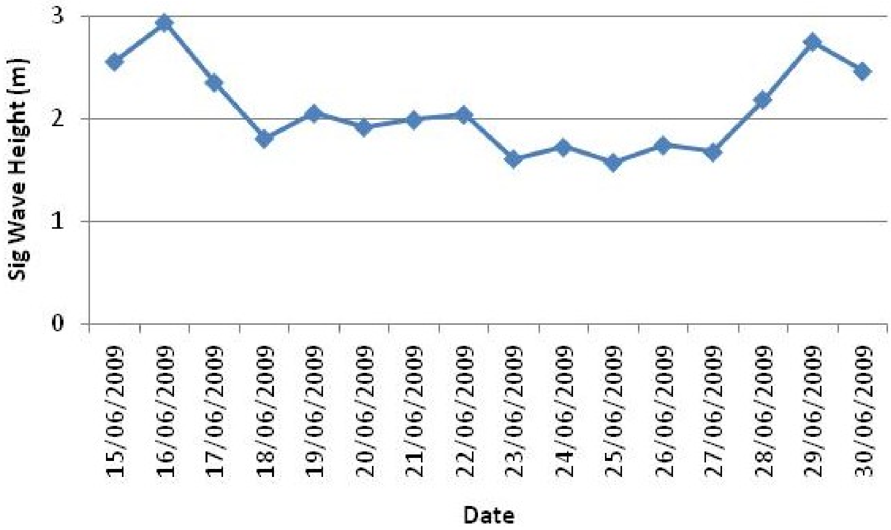


wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the south

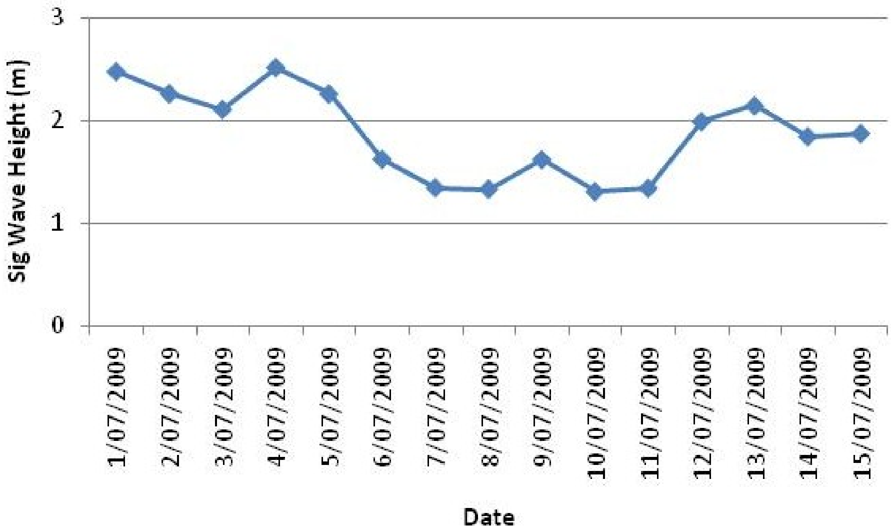


wave refraction diagram of a 2 m high wave with 10 sec interval approaching from the south-southeast

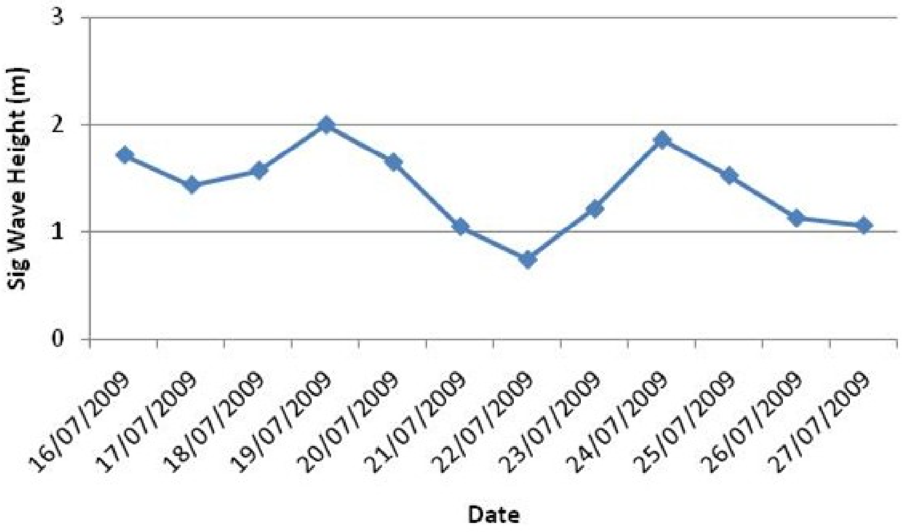
Appendix I: Significant wave heights for the two week periods between field visits



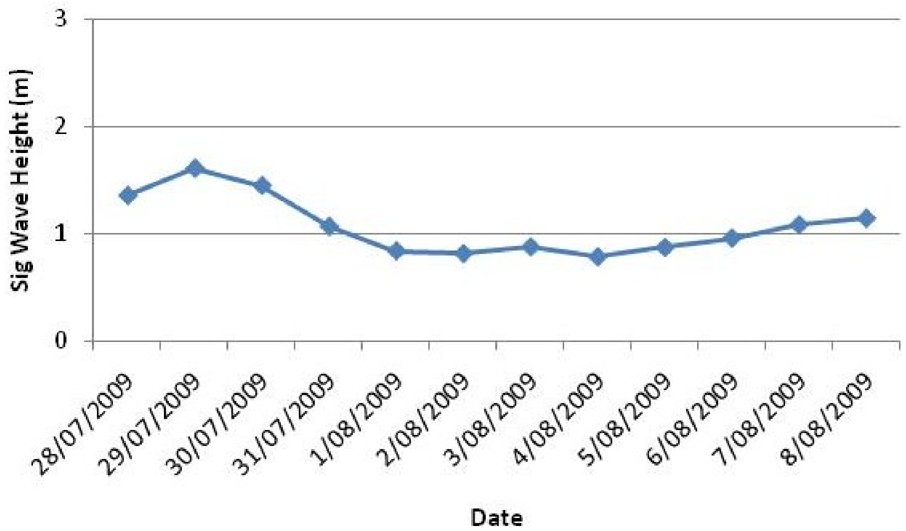
most frequently occurring wave direction is from the south with an average wave height of 2.09 m.



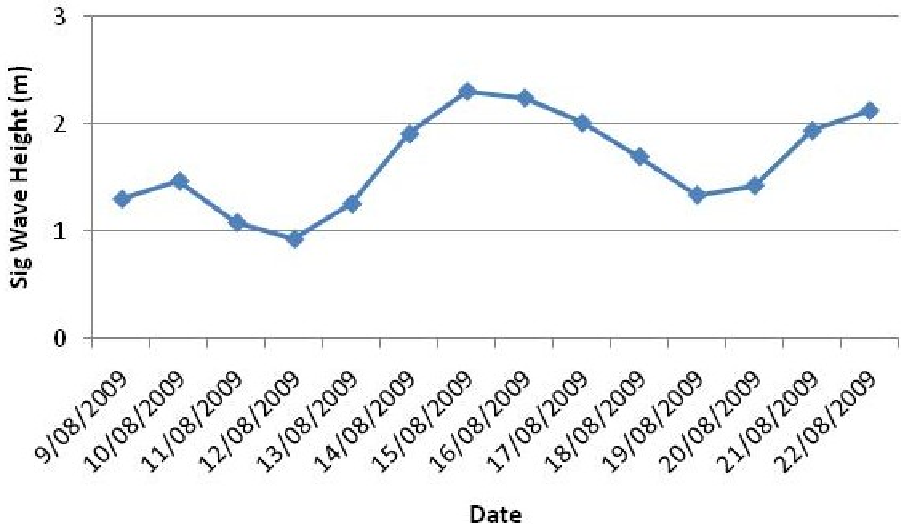
most frequently occurring wave direction is from the east-southeast with an average weave height of 1.87 m.



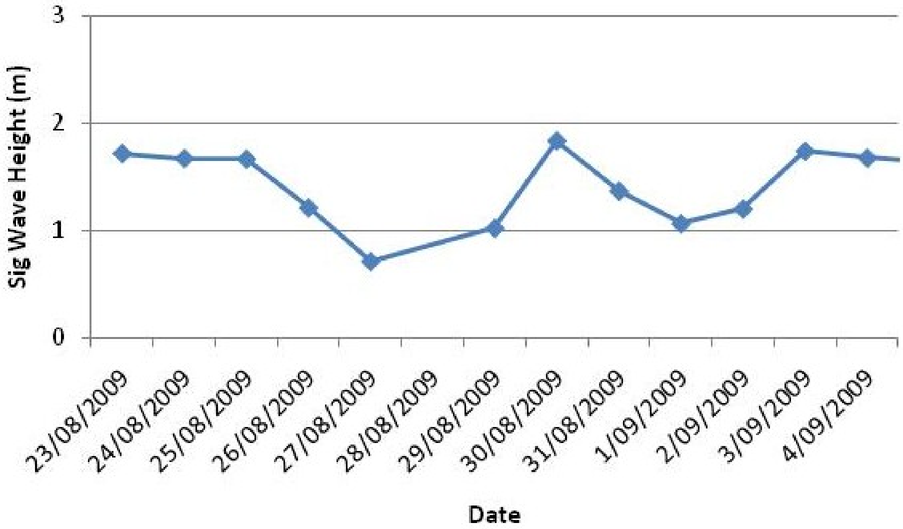
most frequently occurring wave direction ids from the south with an average wave height of 1.41 m.



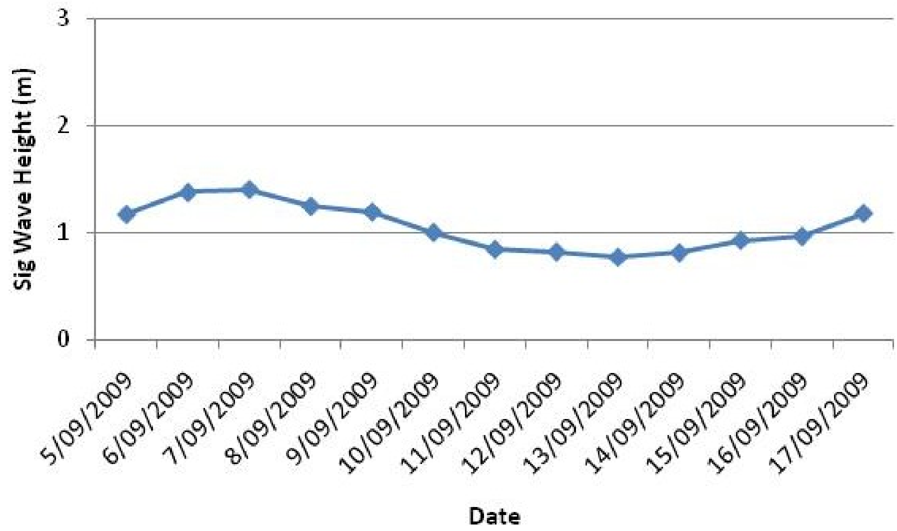
most frequently occurring wave direction is from the south with an average wave height of 1.07 m.



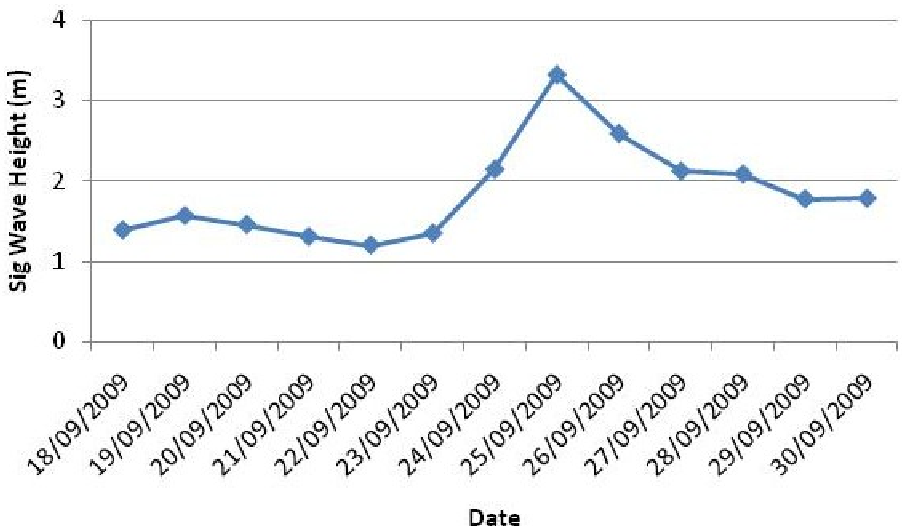
most frequently occurring wave direction is from the east with an average wave height of 1.64 m.



most frequently occurring wave direction is from the east with an average wave height of 1.35 m.



most frequently occurring wave direction is from the northeast with an average wave height of 1.06 m.



most frequently occurring wave height is from the south with an average wave height of 1.85 m.